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Falcon 20 Aircraft Braking Performance on Concrete Runway Surfaces Treated with Potassium Acetate Anti-Icing Fluid

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J. Croll and M. Bastian

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16. Abstract

The braking performance of the NRC Falcon 20 research aircraft was evaluated on concrete runways covered with potassium acetate anti-icing chemical at the Montreal Mirabel airport in March 2004. Tests were conducted with full anti-skid braking without reverse thrust on runway surfaces covered with both a single application (about 36 litres per 1000 square metres) and a double application of potassium acetate, and on runway surfaces covered with water-diluted potassium acetate. Tests were conducted on two different test sections, one at each end of Mirabel runway 11/29. Saab Surface Friction Tester (SFT) vehicles were used to measure the friction of the potassium acetate-covered runway surfaces before and after each aircraft run.

SFT friction values for a single application or water-diluted application of potassium acetate were similar to those for wet runway surfaces. SFT friction values for a double application of potassium acetate were less than those for wet runway surfaces. With full anti-skid braking, the Falcon 20 aircraft braking coefficients on potassium acetate-covered runway surfaces decreased consistently with increasing groundspeed. Mean aircraft braking coefficients varied with the amount and condition of the potassium acetate, consistent with the SFT values, being roughly equivalent to those on wet surfaces for single or water-diluted applications, and less than those on wet surfaces for a double application.

The reduction in Falcon 20 braking coefficients on potassium acetate-covered runways implied increased landing distances and reduced safety margins for landing field length, with magnitudes similar to those determined during tests on wet runways.

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16. Résumé

La performance en freinage de l'avion de recherche Falcon 20 du Conseil national de recherches du Canada (CNRC) sur des pistes en béton recouvertes d'un agent chimique de déglaçage à base d'acétate de potassium a été évaluée à l'Aéroport de Montréal – Mirabel, en mars 2004. Les essais comportaient un freinage maximal avec antipatinage et sans inversion de poussée sur des pistes qui avaient reçu une seule application (environ 36 litres par 1 000 mètres carrés) ou deux applications d'acétate de potassium, et sur des pistes traitées à l'aide d'acétate de potassium dilué dans de l'eau. Les essais ont été menés sur deux sections d'essai distinctes, situées à l'une et l'autre extrémité de la piste 11/29, à Mirabel. Des glissancemètres de Saab prenaient des mesures de la glissance des pistes traitées à l'acétate de potassium avant et après chaque essai de freinage.

Une application unique d'acétate de potassium et l'application du même produit dilué dans de l'eau ont donné des valeurs de glissance semblables à celles obtenues sur des pistes mouillées. Mais deux applications successives d'acétate de potassium faisaient descendre les valeurs de glissance en deçà de celles des pistes mouillées. Aux essais de freinage maximal avec antipatinage, les coefficients de freinage du Falcon 20 sur des pistes traitées à l'acétate de potassium diminuaient en raison inverse de la vitesse sol. Tout comme les valeurs de glissance, les coefficients moyens de freinage de l'avion variaient en fonction de la quantité d'acétate de potassium appliquée et de l'état de celui-ci. Les coefficients obtenus avec une seule application étaient équivalents, plus ou moins, à ceux enregistrés sur des pistes mouillées ou recouvertes d'une solution aqueuse d'acétate de potassium; mais après deux applications, ils étaient inférieurs à ceux enregistrés sur des pistes mouillées.

La diminution des coefficients de freinage du Falcon 20 sur des pistes traitées à l'acétate de potassium signifie, pour ce qui est de la longueur de la piste, des distances d'atterrissage accrues et des marges de sécurité réduites, dans des proportions similaires à celles déterminées au cours des essais sur pistes mouillées.

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GLOSSARY OF TERMS

AFM	Aircraft Flight Manual
AFMLD	Aircraft Flight Manual Landing Distance
AIP	Aeronautical Information Publication
ASTM	American Society for Testing and Materials
ATIS	Automatic Terminal Information System
CAR	Canadian Aviation Regulations
C_D	Aircraft Coefficient of Drag
C_L	Aircraft Coefficient of Lift
C/L	Centreline
CRFI	Canadian Runway Friction Index
CYMX	Montreal Mirabel airport designator
CYOW	Ottawa airport designator
D	Aerodynamic Drag
DA20	Dassault 20 (Falcon)
DAS	Data Acquisition System
D_{CONTAM}	Contamination Drag
D_F	Friction Drag
DGPS	Differential Global Positioning System
D1	Air Distance (from 50 feet to touchdown)
D2	Delay or Transition Distance (from touchdown to brake application)
D3	Braking Distance (from brake application to a complete stop)
ERD	Electronic Recording Decelerometer
ESDU	Engineering Sciences Data Unit
FAA	Federal Aviation Administration
FDR	Flight Data Recorder
ft	Feet
g	Gravitational Constant
GPS	Global Positioning System
HW	Headwind
Hz	Hertz
IAR	Institute for Aerospace Research
IMU	Inertial Measurement Unit
JAR	Joint Aviation Requirements
JWRFMP	Joint Winter Runway Friction Measurement Program
KEAS	Knots Equivalent Airspeed
kn	knots
KTGS	Knots True Groundspeed
L	Aerodynamic Lift
LDA	Landing Distance Available
LFL	Landing Field Length
lbf	Pounds of force
LD	Landing Distance
m	Metres
MOU	Memorandum of Understanding
Mu	Coefficient of friction
MuB	Aircraft Braking Coefficient
NASA	National Aeronautics and Space Administration
PA	Pressure Altitude

psi	pounds per square inch
R^2	Statistical Coefficient of Determination
RFI	Runway Friction Index
RMS	Root Mean Square
RTO	Rejected Takeoff
S	Wing reference area (ft^2)
SD	Standard Deviation
SFT	Surface Friction Tester
SG	Specific Gravity
t	Time
T	Aircraft Thrust
TC	Transport Canada
TS	Test Section
TW	Tradewind
V	Aircraft velocity along the runway
V_{EAS}	Equivalent Airspeed
V_{EFB}	Equivalent Airspeed at Application of Full Brakes
V_{E50}	Equivalent Airspeed at 50 feet Above the Runway Surface
V_G	Groundspeed
V_{GFB}	Groundspeed at Application of Full Brakes
V_{G50}	Groundspeed at 50 feet Above the Runway Surface
V_{REF}	Aircraft Approach Speed
V_{T50}	True Airspeed at 50 feet Above the Runway Surface
W	Aircraft Weight
ε	Runway Slope (positive uphill)
μ_B	Aircraft Braking Coefficient (= Braking Force/(W-L))
μ_{BM}	Mainwheel Braking Coefficient
μ_R	Rolling Friction Coefficient (= Rolling Resistance/(W-L))
$\mu_{t/g\,MAX}$	Maximum Tire-to-ground Braking Coefficient
$\mu_{t/g\,EFF}$	Effective Tire-to-ground Braking Coefficient

FALCON 20 AIRCRAFT BRAKING PERFORMANCE ON CONCRETE RUNWAY SURFACES TREATED WITH POTASSIUM ACETATE ANTI-ICING FLUID

1.0 INTRODUCTION

1.1 Background

Potassium acetate is a chemical that is used for runway anti-icing/deicing at a number of airports in Canada. The chemical is normally applied to ice or packed snow to start a melting and penetration action to help remove the material from the pavement surface, but has been used in recent years as an anti-icing agent as well as a deicing chemical. In the anti-icing mode of operation, runway surfaces are pre-treated with potassium acetate just prior to the onset of freezing precipitation to absorb the moisture and help prevent ice from bonding to the pavement surface.

Recently, concerns have been raised on the effect this chemical may have on runway friction characteristics, particularly when the chemical is applied to bare and dry pavement conditions. Ground friction vehicle tests using a Transport Canada Saab Surface Friction Tester (SFT) are reported in *Friction Testing on Runway Surfaces Sprayed with Potassium Acetate,* Reference 1. These tests showed that the SFT friction coefficient measured on a concrete runway treated with potassium acetate was higher than that measured on an equivalent wet surface (in the self-wetting mode), although this margin decreased with a moderate amount of rubber contamination. Flushing the surface with water in an effort to clean the potassium acetate from the surface resulted in significantly lower SFT friction levels, so there is some concern that the diluted chemical could be quite slippery.

Tests were conducted to determine the braking performance of an FAA B727 aircraft on Type II aircraft deicing fluid in combination with potassium acetate. Test results, reported in *Cert Alert on Effects of Type II Deicing Fluid on Runway Friction*, Reference 2, indicated that the aircraft braking performance on Type II fluid, alone or in combination with potassium acetate, was similar to the braking performance on a wet runway. Potassium acetate was not tested on a smooth (concrete) surface during these tests.

In order to confirm the results of previous tests, the NRC Falcon 20 research aircraft and two Saab SFTs were tested on runway surfaces covered with potassium acetate at the Montreal Mirabel airport in March 2004. Since Falcon 20 tests had previously been conducted on wet runway surfaces at the Mirabel airport (see *Falcon 20 Aircraft Braking Performance on Wet Concrete Runway Surfaces*, Reference 3), the results of the two series of tests could be compared directly.

1.2 Objectives and Scope

This report covers the results of the NRC Falcon 20 braking performance tests on potassium acetate surfaces at the Mirabel airport in March 2004. Tests were conducted only on runway 11/29 since most of the tests in Reference 3 were done on this runway. The specific objectives of the tests were as follows:

a) To determine the aircraft braking coefficients during full anti-skid braking as a function of groundspeed on runway surfaces covered with a layer of potassium acetate; and

b) To determine any effects of different underlying surface textures, rubber contamination or water dilution of potassium acetate.

2.0 EQUIPMENT UNDER TEST

2.1 NRC Falcon 20 Research Aircraft

The NRC-operated Falcon 20, C-FIGD (Figure 1), is a fully instrumented research aircraft well suited for this research program, having participated in aircraft performance testing on wet and contaminated runways under the Joint Winter Runway Friction Measurement Program (JWRFMP). The aircraft was built by Dassault Aviation and is typical of a small business jet. It has two General Electric CF700-2D-2 engines, a maximum takeoff weight of about 27,300 lbs and conventional hydraulically actuated flight controls. Leading and trailing edge wing flaps are used for lift augmentation, and wing-mounted airbrake panels are hydraulically actuated to dump lift after aircraft touchdown. The aircraft does not have reverse thrust capability, but a drag chute is available for emergency stopping assistance.

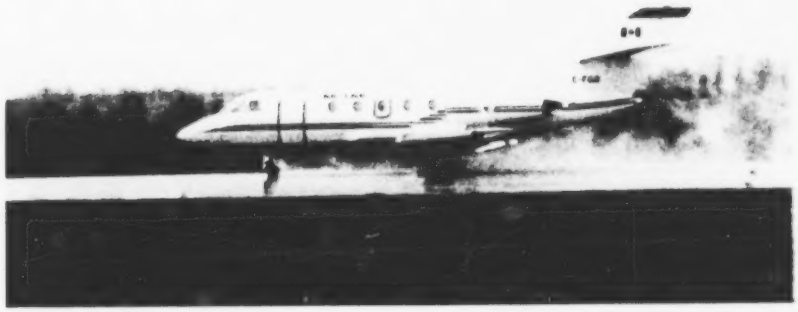

Figure 1 – NRC Falcon 20 on Rain Wet Runway 11 at Mirabel

The Falcon 20 landing gear is conventional with a steerable nose gear fitted with dual 14.5 x 5.5 14 P.R. aircraft tires that have side-mounted chines to deflect spray. Each main gear is fitted with dual 26 x 6.6 14 P.R. aircraft tires with ribbed grooves around the circumference of the tire to channel out water on wet surfaces. Prior to testing, tires were replaced to ensure a minimum of 5 mm groove depth (new tires have 7 mm groove depth). Tire pressure for all tires was 136 psi.

A three disc brake unit is flange mounted to each of the four main wheels, and receives pressure from two independent hydraulic systems. The anti-skid system on the Falcon 20 is a fully adaptive modulating system that automatically controls applied brake pressure to achieve maximum braking effectiveness and safety under all runway conditions. Wheel speed sensors mounted in each wheel axle send signals to the anti-skid control box, which controls anti-skid valves to modulate the brake pressure. Full brake pressure, prior to anti-skid modulation, is 1200 psi. The anti-skid system is inoperative at aircraft groundspeeds below about 17 knots. The Falcon 20 anti-skid system is analogue and was developed in the 1960s. It is considered a "Mark II" system, although it has many of the features associated with "Mark III" systems.

The Falcon 20 has an onboard data acquisition system (DAS) which includes all interfaces for the acquisition and recording of typical flight mechanics parameters, including accelerations, angles and rates in three axes, static and dynamic pressures, brake pressures, main wheel speeds, flight control, trim and throttle positions, and pilot event discrete. All parameters were recorded on a portable hard disk at an update rate of 32 Hz. This was supplemented by manual recording of some parameters such as type of test, configuration, fuel, reported wind direction/speed and pilot qualitative comment.

A NovAtel RT-20 differential global positioning system (DGPS) integrated with a Honeywell HG1700 Inertial Measurement Unit (IMU) was installed in the aircraft as the principal source of aircraft position, velocity and acceleration measurement. For both test periods at Mirabel, the real-time DGPS mode was used, with the ground station receiver and antenna set up to ensure a continuous recording of processed differential GPS data.

2.2 Ground Friction Measurement Vehicles

The Saab Surface Friction Tester (SFT), Figure 2, is a continuous friction measurement device that uses a fifth wheel at a constant slip ratio to measure the surface coefficient of friction. A water tank in the SFT can be used to spray a water film, equivalent to a depth of about 0.5 mm, on the runway surface in front of the fifth wheel. This procedure is used to measure the runway friction in what is called the self-wetting mode. The SFT is used primarily to check the runway surface condition during the summer months to identify the point at which runway maintenance (rubber deposit removal and/or re-surfacing) needs to take place. Corrective maintenance action is required when the average friction index for the entire runway is below 0.50, in accordance with *Aerodrome Standards and Recommended Practices*, Reference 4.

Figure 2 – Saab Surface Friction Tester

Two Saab SFTs were used for the tests at Mirabel, one belonging to Transport Canada and one belonging to Tradewind Scientific Ltd. SFT friction indices were recorded on the potassium acetate covered runway surfaces before and after each aircraft test run. All SFT runs were conducted at test speeds of 65 km/h using an ASTM (American Society for Testing and Materials) E1551 test tire. Test results were compared to the SFT friction indices recorded during the Reference 3 tests on wet runways and on dry runways (in the self-wetting mode).

An Electronic Recording Decelerometer (ERD), Figure 3, was also used during the tests at Mirabel. The ERD is a spot measurement device that measures deceleration. The device is rigidly mounted in the cab of an airport vehicle, and readings are taken by accelerating the vehicle to 50 km/h and then applying the brakes to the point of wheel lockup. A number of measurements are taken at various intervals on each side of the runway centreline, and averaged to provide a single friction value for the entire runway surface. The ERD is used on winter contaminated runway surfaces to help predict aircraft braking coefficient, but is not normally used on wet surfaces. ERD runs were done on some of the potassium acetate covered surfaces to check for consistency of measurement and possible application to aircraft braking performance prediction.

Figure 3 - Electronic Recording Decelerometer (ERD) Mounted in a Chevy Blazer

3.0 TEST PROCEDURES

Test sections were set up on either end of runway 11/29, depending on the prevailing wind, starting about 500 m from the threshold and ending at about 1200 m from the threshold. Start and end points of the test sections were marked by cone markers placed on each edge of the runway. The widths of the test sections were about 60 feet (18 m) centered on the 200 foot (60 m) wide runway.

The day prior to the aircraft test runs, the two SFTs conducted calibration runs on a wet surface laid by a water tanker on the runway 11 test section. Following these runs, the water was removed and the test section swept to return the surface to a bare and dry condition prior to the application of potassium acetate during the next days tests. Aircraft taxi runs were also conducted along the full length of runway 11/29 in both directions to provide rolling friction data, idle thrust calibrations and runway slope data for use in the data analysis program.

A truck containing a tank of potassium acetate, shown in Figure 4, was used to apply the chemical to the runway prior to the aircraft runs. A single application of chemical was deemed to consist of one pass down the centreline of the test section in each direction, dispensing a total of about 450 litres of chemical. This equated to an application rate of about 36 litres per 1000 m^2, about double the application rate of 20 litres per 1000 m^2 used in the Reference 1 tests with the SFT.

The SFTs measured the surface friction immediately after the application of the potassium acetate. The aircraft then conducted one or two acceleration-stop manoeuvres (rejected takeoff, or RTO) in the test section, followed by a takeoff on the dry portion of the runway. The aircraft flew an 8 to 10 minute circuit with the landing gear extended for brake cooling, and then conducted a full stop landing in the test section. Full anti-skid braking was initiated upon each entry into the test section and was released just prior to exit from the test section. Following the aircraft runs, the SFTs measured the surface friction on the potassium acetate remaining on the surface of the test section.

On the runway 11 test section, a second application of potassium acetate was tested after the first series of tests, whereas on the runway 29 test section, only a single application of potassium acetate was tested. Following the tests on the undiluted potassium acetate, the chemical was diluted with water, using a water tanker, to simulate the effects of light precipitation. SFT readings were again recorded following preparation of the test section, and between each aircraft acceleration-stop or landing. Test sections were also inspected by ground personnel between aircraft runs to ensure that no unusual conditions had

developed as a result of the aircraft run, such as skid marks or foreign objects, and that no significant areas of standing water or diluted chemical had formed.

Figure 4 – Potassium Acetate Truck Applying Chemical to Runway 29 Test Section

Throughout the tests, safety procedures were followed in accordance with the test plan, entitled *NRC Falcon 20 Aircraft Performance Tests on Runway Surfaces Treated with Potassium Acetate,* Reference 5. A ground test coordinator maintained radio contact with the airport ground control, test aircraft and ground vehicles, and ensured coordination of all vehicle movements and observation of the aircraft test runs. Photographic records of the various surface conditions were collected.

4.0 DATA ANALYSIS METHODS

The aircraft braking coefficient is defined as the total horizontal force due to wheel braking friction divided by the vertical component of the aircraft weight on all wheels (including those without brakes). With a fully active anti-skid system, it is understood that the term "aircraft braking coefficient" refers to the "effective" aircraft braking coefficient of friction, which includes any inefficiencies of the anti-skid system.

For the continuous full anti-skid braking runs conducted on potassium acetate surfaces during this test program, the aircraft braking coefficients (Mu braking or μ_B) were determined from an equation for aircraft deceleration along the runway and plotted against the aircraft groundspeed. Detailed analysis methods are contained in the report, *Braking Friction Coefficient and Contamination Drag Obtained for a Falcon 20 Aircraft on Winter Contaminated Runway Surfaces,* Reference 6. The equations are summarized as follows:

$$\mu_B = \left(\frac{T}{W} - \frac{D}{W} - \frac{D_{CONTAM}}{W} - \varepsilon - \frac{1}{g}\frac{dV}{dt}\right) \Big/ \left(1 - \frac{L}{W}\right) \qquad (1)$$

where μ_B = aircraft braking coefficient
T = engine thrust
W = aircraft weight
D = aerodynamic drag
D_{CONTAM} = contamination drag
ε = runway slope (+ve uphill)

V = velocity along the runway
dV/dt= acceleration along the runway
g = gravitational constant
L = aerodynamic lift

The parameter D_{CONTAM}/W in equation (1) can be set to zero for runways with less than 3 mm depth of fluid where displacement drag and impingement drag are both considered to be insignificant. Without braking, equation (1) reduces to the rolling friction coefficient, μ_R, as follows:

$$\mu_R = \left(\frac{T}{W} - \frac{D}{W} - \varepsilon - \frac{1}{g}\frac{dV}{dt}\right) \Big/ \left(1 - \frac{L}{W}\right) \tag{2}$$

Equations for the aerodynamic lift and drag are as follows:

$$L = \frac{1}{2}\rho_o V_{EAS}^2 S C_L$$
$$D = \frac{1}{2}\rho_o V_{EAS}^2 S C_D \tag{3}$$

where ρ_o = $0.002377 slug/ft^3$
V_{EAS} = equivalent airspeed $(ft/sec) = 1.688 \times V_{EAS}\,(knots)$
C_L = lift coefficient in ground effect, ground attitude
C_D = drag coefficient in ground effect, ground attitude, and
S = wing reference area (ft^2)

For the NRC Falcon 20, $S = 441.1\ ft^2$, and C_L and C_D are 0.30 and 0.132 respectively in the landing configuration (flaps 40°, airbrakes out) and 0.10 and 0.076 respectively in the rejected takeoff (RTO) configuration (flaps 15°, airbrakes out).

Engine thrust at idle power for the Falcon 20 was modelled as a linear function of V_{EAS} (knots):

$$T = 600 - 4.62\,V_{EAS} \quad (lbf) \tag{4}$$

In this report, the aircraft braking coefficients μ_B on potassium acetate surfaces will be compared directly with those obtained on wet runway surfaces, without conversion to an equivalent mainwheel braking coefficient for the Falcon 20. The mainwheel braking coefficient is the effective horizontal decelerating force due to friction at each mainwheel (with full anti-skid braking) divided by the vertical component of the weight on each mainwheel. This parameter was compared to Federal Aviation Regulation (FAR) data for aircraft certification on wet runways in Reference 3, *Falcon 20 Aircraft Braking Performance on Wet Concrete Runway Surfaces*.

5.0 RESULTS AND DISCUSSION

Testing was accomplished at the Mirabel airport during a three day period in March 2004. On the first test day, prior to the arrival of the aircraft, comparative tests were done between the two Saab SFTs on the runway 11 test section. These tests were done on a surface that was sprayed lightly by a water tanker to simulate the SFT self-wetting mode, which could not be used with the ambient temperatures being close to the freezing point. Aircraft testing on the second and third day comprised a total of eleven full anti-skid braking runs, four on surfaces with a single application of potassium acetate, two on a surface with a

double application of potassium acetate, and five on surfaces with water diluted potassium acetate. Friction readings were recorded by both SFTs before and after each aircraft run, and ERD friction readings were recorded on selected surfaces.

5.1 Ground Friction Measurements

The results of the comparative tests between the Transport Canada (TC) SFT and the Tradewind Scientific Inc. (TW) SFT are shown in Figures 5 and 6. The friction readings, expressed as a coefficient between 0 and 1, are plotted for each 100 m interval over the length of the test section. Both SFTs were run sequentially in the runway 11 direction about 3 m left (north) of the runway centreline (C/L), and then back in the runway 29 direction about 3 m left (south) of the runway C/L. The test loop was then repeated. Figure 5 is plotted for the four runs made on the north side of the runway C/L, while Figure 6 is plotted for the four runs made on the south side of the runway C/L. All runs were made within a 15 minute period on a tanker wet surface.

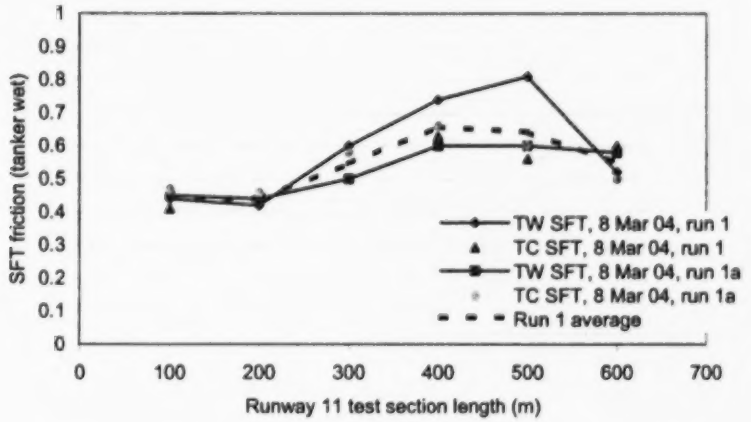

Figure 5 – SFT Friction, Runway 11 Test Section, North of C/L

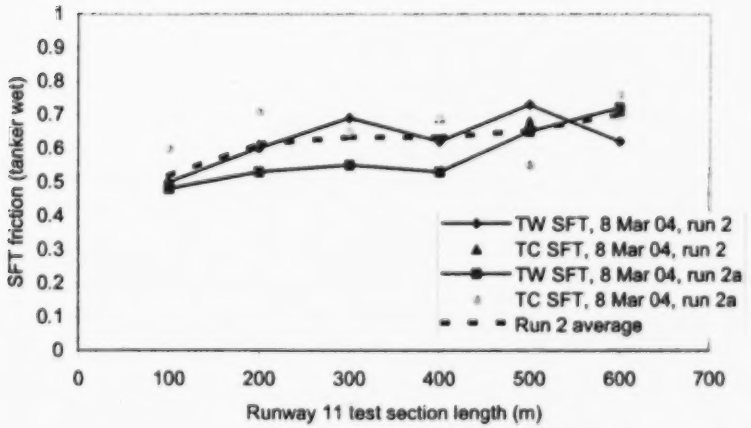

Figure 6 – SFT Friction, Runway 11 Test Section, South of C/L

The data in Figure 5 for the north side of the runway are fairly consistent, within about ± 0.04 units, with the exception of run 1 for the TW SFT, which deviates more than 0.10 units above the average at the 400 m and 500 m points. The average SFT friction varies along the length of the test section from a low of 0.44 in the first 200 m to a high of 0.65 at the 400 m and 500 m points. The mean friction reading for the north side of the runway 11 test section was 0.55.

The data in Figure 6 for the south side of the runway show more variance, about ± 0.08 units, than those for the north side of the runway. The average SFT friction varies along the length of the test section from a low of 0.52 at the beginning of the test section to a high of 0.70 at the end of the test section. The mean friction reading for the south side of the runway 11 test section was 0.63.

With a repeatability uncertainty of about ± 0.07 for the Saab family of friction measurement devices (see *Repeatability and Reproducibility of Saab Friction Measurement Devices in Self-Wet Mode*, Reference 7), the variations from the averages in Figures 5 and 6 are not unexpected. Friction measurements also varied across the runway centreline and along the length of the test section due to differences in runway texture, rubber contamination and degree of wetness for the tanker sprayed layer of water. Variations also occurred between the TW and TC SFTs, due to differences in test tire configuration and differences in the actual track driven by the vehicles down the runway.

The SFT readings taken on potassium acetate surfaces between aircraft runs are shown in Appendices A and B, and summarized in Table 1. The SFT average readings were interpolated to match the aircraft run times and may differ slightly from the raw recorded values. SFT measurements on potassium acetate surfaces were also subject to uncertainties, which must be considered when establishing any comparisons with aircraft performance data.

Table 1 – Summary of Saab SFT Friction Readings

	Tanker Wet	One application potassium acetate	Two applications potassium acetate	Water diluted potassium acetate
Runway 11 test section	0.55 - 0.63	0.57 – 0.61	0.48 – 0.54	0.52 – 0.64
Runway 29 test section		0.67 – 0.71		0.57 – 0.68

The SFT readings shown in Table 1 for runway 11 indicate that the friction on a surface with a single application of potassium acetate was about the same as the friction on a tanker wet surface. Since previous tests (Reference 3) on the same runway showed the SFT friction on tanker wet surfaces to be slightly higher than that obtained on rain wet surfaces (moderate continuous rain) or for self-wetting, the friction on a surface with a single application of potassium acetate would be at least as high as that on a rain wet surface. For runway 11, the SFT friction on a surface with a double application of potassium acetate was less than that on a tanker/rain wet surface, and the SFT friction on a surface covered with water diluted potassium acetate was about the same as that on a tanker/rain wet surface.

The SFT friction on runway 29 with a single application of potassium acetate was quite high, but no tanker wetting tests were done on this runway for comparison. Previous tests (Reference 3) showed the SFT self-wetting friction on runway 29 to actually be slightly less (0.50 – 0.52) than that for runway 11 (0.50 – 0.58). The reason for the relatively high SFT friction on potassium acetate is unknown, but suspected to be the result of a thinner application on runway 29 than on runway 11, as noted in section 5.2.3. The SFT friction on runway 29 with water diluted potassium acetate was slightly higher than that for runway 11.

A Transport Canada ERD was run on some of the potassium acetate surfaces to check for consistency of measurement and to compare the CRFI with SFT measured friction. For runway 11, average CRFI values of 0.52 and 0.58 were recorded on a double application of potassium acetate and on water diluted potassium acetate, respectively. These values are consistent with the SFT readings in Table 1. For runway 29, average CRFI values of 0.55 and 0.67 were recorded on a single application of potassium acetate and on water diluted potassium acetate, respectively. These values are not consistent with the SFT readings in Table 1, the first value being low and the second value being high. The limited ERD data obtained were insufficient to confirm the usefulness of the ERD on potassium acetate surfaces.

5.2 Aircraft Braking Coefficients

Appendix A is a summary of all the aircraft test runs, including the braking runs and the taxi tests. Page A1 tabulates the test conditions for each run, and pages A2 through A8 show time histories of the left and right brake pressures (psi), aircraft groundspeed (knots) and aircraft braking coefficient (MuB, or μ_B) for each run. The time histories include the raw unfiltered data collected at 32 samples per second, with the parameter μ_B calculated from equation (1) in section 4.0 of this report. For the taxi runs the brake pressures are zero, and μ_B reduces to the aircraft rolling friction coefficient.

Appendix B is a summary of the braking test runs used to determine the aircraft braking coefficients. Page B1 tabulates the test conditions for each braking run, as well as the mean SFT friction value, the mean aircraft groundspeed, the mean aircraft μ_B, and the coefficients for a linear regression between a smoothed aircraft μ_B parameter and the aircraft groundspeed. Pages B2 to B7 show the variation of the smoothed μ_B parameter with aircraft groundspeed for each braking run. The smoothed μ_B parameter is calculated by taking a one second average (16 samples on either side) of each recorded μ_B sample. This procedure filters out the variations of μ_B resulting from anti-skid action, but retains the variations of μ_B resulting from changes in surface friction or texture.

In the following sections, the variation of aircraft braking coefficients on runway surfaces covered with potassium acetate will be examined as a function of mean aircraft brake pressures, SFT measured friction values and aircraft groundspeed. The resulting relationships will be compared to those determined for wet runways.

5.2.1 Aircraft Braking Coefficients versus Mean Brake Pressure

The brake pressure time histories are plotted in Appendix A for each run. An anti-skid system modulation frequency of about 4-5 Hz can be observed for most of the runs, resulting in mean brake pressures from about 300 psi to just under 700 psi, well below the torque limit of 1200 psi. The brake pressures vary from run to run as a function of surface texture, potassium acetate condition (single application, double application or water diluted), and aircraft groundspeed, as do the aircraft braking coefficients μ_B. Figure 7 is a plot of the mean aircraft braking coefficients μ_B against the mean brake pressures for the 11 runs on potassium acetate surfaces.

Figure 7 also includes a total of 30 braking runs on wet runway surfaces (brake pressures less than 700 psi) and two braking runs on dry surfaces (brake pressures of about 900 psi and 1100 psi), all reported in Reference 3. An excellent linear correlation is shown, with a coefficient of determination R^2 of over 97%. The runs on potassium acetate surfaces compare well with those on the wet surfaces, having a similar range of brake pressures and braking coefficients. A similar relationship is shown between the two parameters, with the braking coefficients on potassium acetate surfaces slightly lower than those on wet surfaces for equivalent brake pressures. This effect could be due to the differences in physical properties

between potassium acetate and water, or slight differences in aircraft tire/anti-skid configurations between the two test periods.

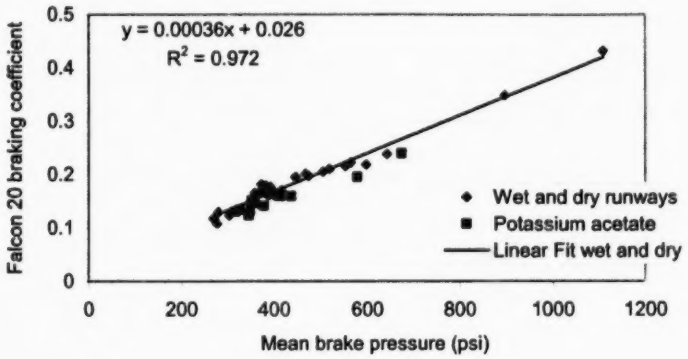

Figure 7 – Falcon 20 Braking Coefficient versus Mean Brake Pressure

5.2.2 Aircraft Braking Coefficients versus SFT Measured Friction

Figure 8 shows the mean aircraft braking coefficients μ_B plotted against the SFT friction indices for the 11 braking runs on potassium acetate surfaces listed in Appendix B, as well as the braking runs on wet runway surfaces conducted in the years 2002 and 2003. Because the values of μ_B also vary with groundspeed, as will be discussed in detail in the next section, the values of μ_B in Figure 8 have been normalized to a common groundspeed of 66 kn, which is the approximate average for all the runs. The values of μ_B (66 kn) were determined by adjusting the mean aircraft braking coefficients up or down along the gradient of μ_B versus groundspeed for each particular run, shown in Appendix B.

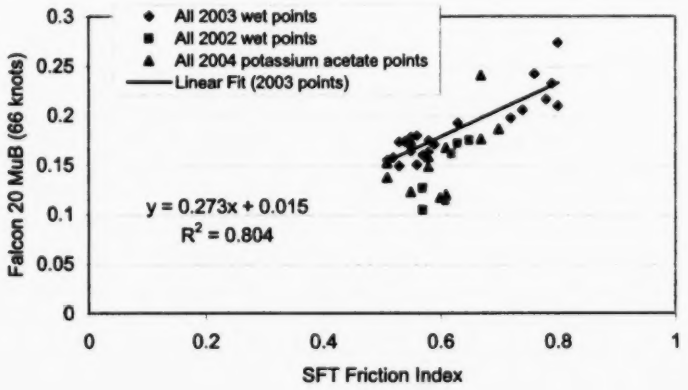

Figure 8 – Falcon 20 Braking Coefficient versus SFT Friction Index

As discussed in Reference 3, there are two clusters of data in Figure 8 for the wet runway points, separated primarily due to differences in runway texture. The right hand cluster at SFT values between 0.7 and 0.8 represents all test points on Mirabel runway 06/24, while the left hand cluster at SFT values between 0.5 and 0.7 represents all test points on Mirabel runway 11/29. The data for potassium acetate, having being obtained on Mirabel runway 11/29, is comparable only to the left hand cluster of points on wet surfaces.

The linear fit line for the 2003 wet runway data (both clusters) shows a fair correlation, with a coefficient of determination $R^2 = 0.80$, indicating that the SFT vehicle can be used as a rough measure of the effects of differing surface texture. For a given surface texture, however, there is a poor correlation between aircraft μ_B and SFT friction index for differing degrees of wetness or potassium acetate conditions. This can be seen by taking each data cluster in Figure 8 in isolation. The left data cluster, for instance, shows variations in aircraft μ_B between about 0.10 and about 0.20 for SFT friction values between 0.50 and 0.70.

The aircraft μ_B values for the potassium acetate surfaces were slightly lower than those for wet runway surfaces at SFT friction values between 0.5 and 0.7. The two points with the lowest SFT values of 0.51 were both recorded on a double application of potassium acetate on runway 11, but did not produce the lowest aircraft μ_B values. The three lowest aircraft μ_B values of about 0.12 in Figure 8 were recorded for different potassium acetate surface conditions; a water diluted double application on runway 11 (SFT=0.55), a single application on runway 11 (SFT=0.60) and a water diluted single application on runway 29 (SFT=0.61). For a given runway surface texture, aircraft μ_B correlated poorly with SFT friction index on potassium acetate surfaces, similar to the results on wet runways.

5.2.3 Aircraft Braking Coefficients versus Groundspeed

The variation of aircraft braking coefficient with groundspeed on potassium acetate surfaces was expected to be similar to that on wet surfaces. On wet runway surfaces, trapped water enters the leading edge of the aircraft tire-to-ground contact area, and gives rise to a lift force acting to separate the tire from the base surface (see *Friction Fundamentals, Concepts and Methodology*, Reference 8). As groundspeed increases, the tire-to-ground contact area and coefficient of friction decrease, becoming approximately zero at the critical hydroplaning speed. Aircraft braking coefficients tend to decrease with increasing groundspeed on wet surfaces, compared to being relatively constant with changing groundspeed on dry surfaces. Plots of aircraft μ_B versus groundspeed have a negative slope which tends to become more negative with increasing water depth, as described in *Behaviour of Aircraft Anti-skid Braking Systems on Dry and Wet Runway Surfaces,* Reference 9.

Plots of smoothed μ_B versus aircraft groundspeed for each run on potassium acetate surfaces are shown in Appendix B, pages B2 through B7. The regression coefficients for the runs are listed in the table on page B1. All of these coefficients indicate a negative slope, as expected, although some are steeper than others. The vertical axis intercepts, also shown on page B1, vary considerably from run to run.

As noted in Reference 3, the relationship between aircraft μ_B and groundspeed derived from single braking runs can be significantly affected by local variations in runway texture and/or wetness. Thus, runs will be combined for each condition of potassium acetate (single or double application, or water diluted), and the resulting relationship between μ_B and groundspeed will be compared to that obtained on wet surfaces. The baseline used for wet surfaces will be the relationship between aircraft μ_B and groundspeed derived for all six runs conducted in rain wet conditions on the Mirabel runway 11 test section, taken from Reference 3. The linear relationship is as follows:

$$\mu_B(rain\ wet) = 0.237 - 0.00103 \times V_G \qquad \text{(Runway 11, } V_G \text{ in knots)} \qquad (5)$$

Figure 9 shows the plots of aircraft μ_B versus groundspeed for both runs conducted on a single application of potassium acetate on the Mirabel runway 11 test section (flight 2004/1, runs 2 and 3). The aircraft μ_B values for run 2 were considerably less than those for run 3. Run 2 was the first accelerate-stop maneuver done for this series of tests, and the aircraft was allowed to deviate to the left (north) side of the runway centreline, which had a lower SFT baseline friction than for the south side. Run 2 was also started at relatively low speed, and completed within the first 300 m of the test section, where SFT friction was

between 0.4 and 0.5 (see Figure 5). Run 3 was conducted on the runway centreline, and was less influenced by areas of low friction. The linear fit shown for run 3 is very close to the relationship shown in equation (5) for rain wet surfaces.

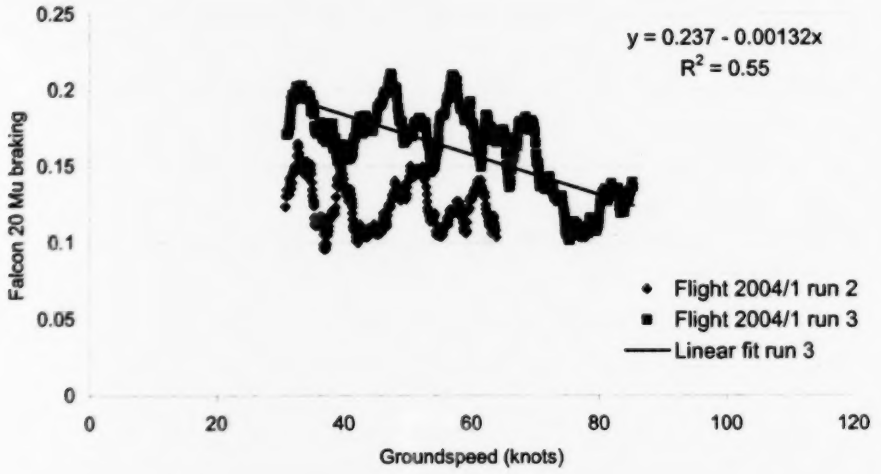

Figure 9 – Falcon 20 Mu Braking vs Groundspeed, Runway 11, Single Potassium Acetate Application

Figure 10 shows the plots of aircraft μ_B versus groundspeed for both runs conducted on a double application of potassium acetate on the Mirabel runway 11 test section (flight 2004/1, runs 4 and 5). The aircraft μ_B values were similar for both of these runs, which were both landings and used up the full 700m of the test section. The y-axis intercept for the linear fit is lower than that for rain wet surfaces (equation 5), but the slope is not as steep. Qualitatively, the braking performance was judged significantly less than that on a single application of potassium acetate, although these two runs were done at higher speed than the first two runs.

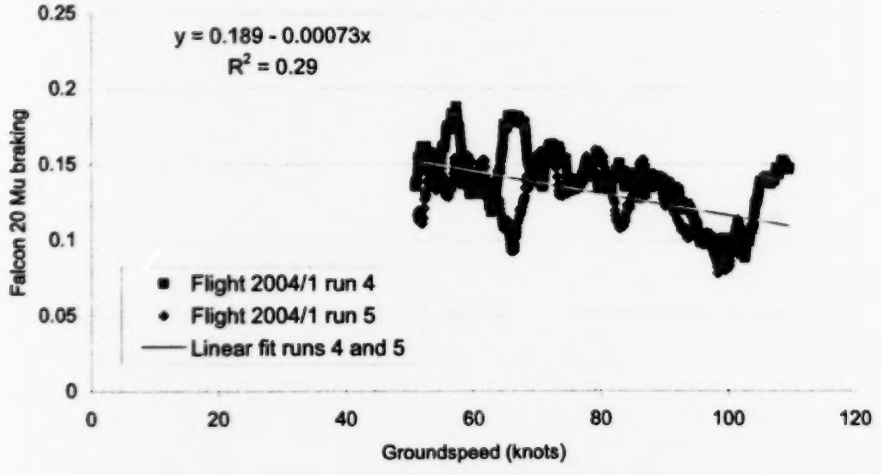

Figure 10 – Falcon 20 Mu Braking vs Groundspeed, Runway 11, Double Potassium Acetate Application

Figure 11 shows the plots of aircraft μ_B versus groundspeed for the three runs conducted on a water diluted double application of potassium acetate on the Mirabel runway 11 test section (flight 2004/1, runs 6, 7 and 8). The aircraft μ_B values were slightly less on run 6 than they were for runs 7 and 8, possibly due to the higher degree of wetness on the first run than on the subsequent runs, which were affected by evaporation (water was not re-applied between runs). The y-axis intercept for the linear fit is lower than that for rain wet surfaces (equation 5), and the slope is slightly shallower. Qualitatively, the braking performance was judged to be about the same as that on a wet runway surface.

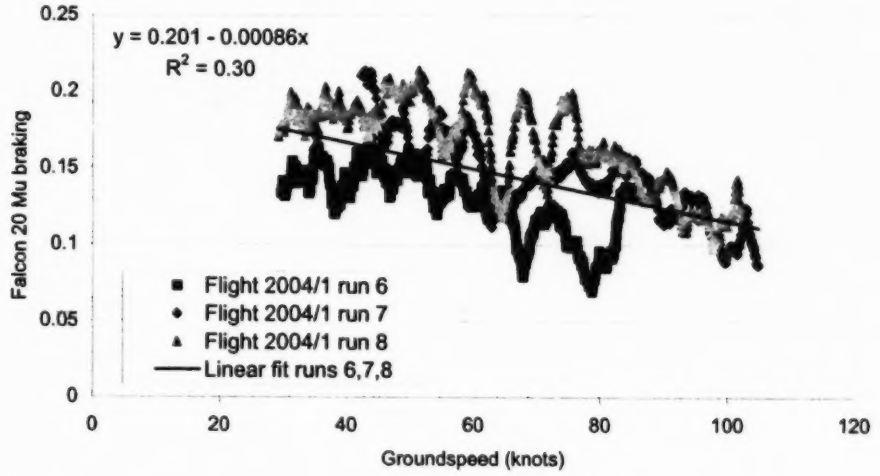

Figure 11 – Falcon 20 Mu Braking vs Groundspeed, Runway 11, Water Diluted Potassium Acetate

Figure 12 shows the plots of aircraft μ_B versus groundspeed for both runs conducted on a single application of potassium acetate on the Mirabel runway 29 test section (flight 2004/2, runs 2 and 3). The linear fit shown for run 2 is very close to the relationship shown in equation (5) for rain wet surfaces. The aircraft μ_B values for run 3 were considerably higher than those for run 2, even at the higher speeds. Both runs were done in the same area of the test section, and the reason for differences in braking is unknown.

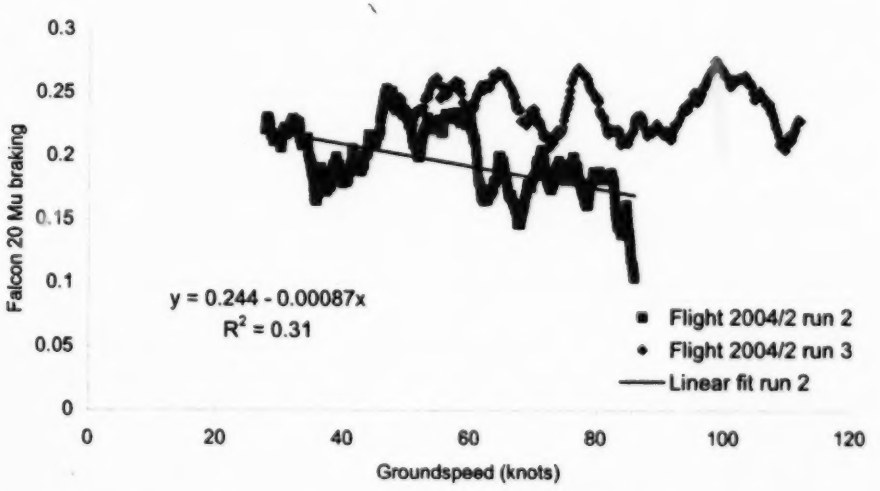

Figure 12 – Falcon 20 Mu Braking vs Groundspeed, Runway 29, Single Potassium Acetate Application

Figure 13 shows the plots of aircraft μ_B versus groundspeed for the two runs conducted on a water diluted single application of potassium acetate on the Mirabel runway 29 test section (flight 2004/2, runs 4 and 5). The aircraft μ_B values were higher on run 5 than they were for run 4, again possibly due to the higher degree of wetness on the first run than on the subsequent run. The y-axis intercept for the linear fit is lower than that for rain wet surfaces (equation 5), but the slope is very shallow. Qualitatively, the braking performance was judged to be about the same as that on a wet runway surface.

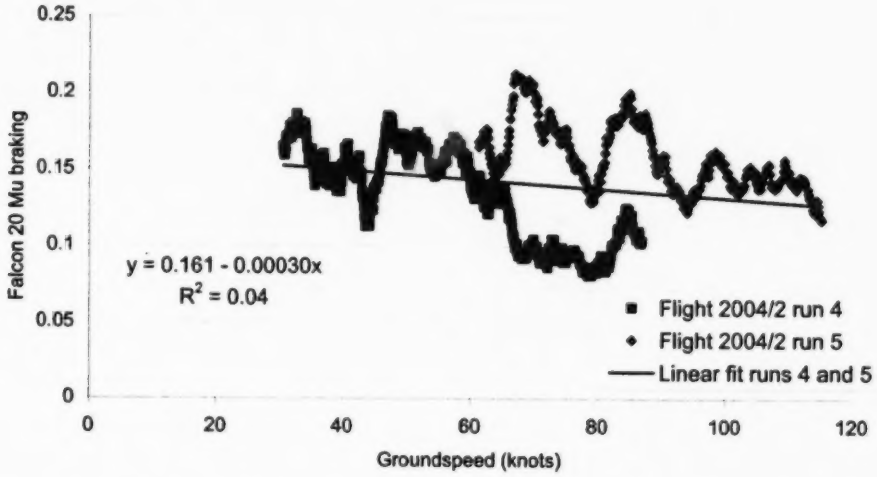

Figure 13 – Falcon 20 Mu Braking vs Groundspeed, Runway 29, Water Diluted Potassium Acetate

A comparison of the two runway test sections with a single application of potassium acetate shows that the Falcon 20 braking coefficients were higher on the runway 29 test section (Figure 12) than they were on the runway 11 test section (Figure 9). This is also evident from the column of mean μ_B shown in the table in Appendix B, page B1. The difference in braking performance was not expected, since the surface textures of the two test sections were about the same. The test section friction profiles, measured in the Reference 3 tests, actually showed a slightly lower mean SFT friction value (0.51) for runway 29 than for runway 11 (0.54). The higher braking coefficients on runway 29 are therefore suspected to be a result of a thinner application of potassium acetate to runway 29 than to runway 11, and not a function of differing runway texture. Records of application rates and volumes needed to verify this were unfortunately incomplete. The higher aircraft braking coefficients were consistent with the higher SFT friction readings on runway 29 shown in Table 1, page 8.

Since a double layer of potassium acetate was applied only to the runway 11 test section, comparisons cannot be made with runway 29. However, in comparison with the single application of potassium acetate on runway 11 (run 3, Figure 9, with run 2 discounted for the reasons stated previously), the braking coefficients decreased for the double application (Figure 10). This is consistent with the lower mean μ_B shown in the table in Appendix B, page B1, and with the lower SFT friction readings for this condition shown in Table 1, page 8.

The addition of water to the double application of potassium acetate on runway 11 resulted in a slight increase in the aircraft μ_B, as shown by a comparison of Figure 11 with Figure 10 and by the mean μ_B shown in the table in Appendix B, page B1. The addition of water to the single application of potassium acetate on runway 29 resulted in a slight decrease in the aircraft μ_B, as shown by a comparison of Figure 13 with Figure 12 and by the mean μ_B shown in the table in Appendix B, page B1. Since the aircraft μ_B

on the undiluted potassium acetate was quite a bit lower on runway 11 (due to the double application) than on runway 29 to begin with, the effect of water dilution was to roughly equalize the braking performance on the two test sections.

The average SFT friction readings on the water diluted potassium acetate, shown in Table 1, page 8, were consistent with the trends in the aircraft μ_B as described above. The addition of water to a double application of potassium acetate on runway 11, which had an initial SFT friction less than that of a wet surface, increased the SFT friction of the diluted condition closer to that of a wet surface. The addition of water to a single (but thinner) application of potassium acetate on runway 29, which had an initial SFT friction higher than that of a wet surface, decreased the SFT friction of the diluted condition closer to that of a wet surface.

Since the Falcon 20 braking coefficients on potassium acetate surfaces are approximately equal to, or even slightly less than those on rain wet surfaces, a review of the resulting aircraft stopping distances and landing field lengths, taken from Reference 3, is undertaken in the next few paragraphs.

5.3 Aircraft Stopping Distance and Landing Field Length

The safety margins for landing on wet or potassium acetate runways at destination or alternate airports can be assessed by calculating the aircraft stopping distances D3 for various aircraft weights, and comparing these to landing field lengths (LFL) determined from Aircraft Flight Manual Landing Distances (AFMLD). The relationship in equation (1) is used to determine the aircraft deceleration profile at various weights and values of μ_B for both wet and dry runway surfaces. The deceleration profile is then used to determine aircraft stopping distance.

Rearranging equation (1) with the runway slope (ε) and contamination drag (D_{CONTAM}) equal to zero, and with values of lift (L), drag (D) and thrust (T) inserted for the Falcon 20 in the landing configuration, the equation for aircraft acceleration in "g" units becomes:

$$\frac{1}{g}\frac{dV}{dt} = \frac{600}{W} - \mu_B - \frac{4.62}{W} \times V_{EAS} + \left(\frac{-0.1976}{W} + \frac{0.4492}{W} \times \mu_B\right) \times V_{EAS}^2 \qquad (6)$$

where V_{EAS} is the aircraft equivalent airspeed in knots and W is the aircraft weight in lbf. For wet or potassium acetate surface conditions, the braking coefficient (μ_B) itself is a function of aircraft groundspeed as shown in equation (5), so equation (6) becomes a third order function of aircraft velocity. In this case, stopping distance is more accurately computed using a numerical integration technique, as opposed to using the average acceleration method. For dry runways, with μ_B independent of groundspeed, the average acceleration method provides sufficient accuracy.

Table 2 contains a comparison of Falcon 20 stopping distances (D3) on wet and dry runways calculated for typical values of AFMLD. See NRC Report, *Evaluation of Aircraft Braking Performance on Winter Contaminated Runways and Prediction of Aircraft Landing Distance Using the CRFI*, Reference 10, for details on stopping distance calculation. A value of $\mu_B = 0.43$ is used for the dry runway calculations, and the value of μ_B given by equation (5) is used for the wet or potassium acetate runway calculations. All distances are expressed in feet.

Table 2 – Comparison of Falcon 20 Stopping Distances on Wet and Dry Runways

W (lb)	PA (ft)	HW (kn)	V_{REF} (kn)	AFMLD	V_{GFB} (kn)	D3 (dry)	D1+ D2	D3 (wet)	LD (wet)
18,000	0	5	109.2	2000	91.1	884	1116	1917	3033
20,700	0	0	117.1	2400	104.0	1144	1256	2570	3826
25,400	0	0	129.7	2800	116.6	1425	1375	3279	4654
25,200	6000	0	129.2	3200	128.2	1723	1477	4196	5673

The following terms are used in Table 2:

W = aircraft weight
PA = pressure altitude
HW = headwind
V_{REF} = reference airspeed on approach
V_{GFB} = groundspeed at the start of full wheel braking
D3 = stopping distance from start of wheel braking to a complete stop
D1+D2 = sum of air distance and transition distance
LD (wet) = total landing distance on a wet runway = D1+ D2+ D3 (wet)

The dry landing distances (AFMLD) and wet landing distances shown in Table 2 contain no safety factors. The value for (D1+D2) is determined by simply subtracting D3 (dry) from the AFMLD. This value of (D1+D2) is then added to D3 (wet) to obtain the wet landing distance. The value of D3 (wet) is based on the actual aircraft μ_B obtained during the Falcon braking runs on rain wet concrete runway 11 at Mirabel, roughly equivalent to the aircraft μ_B obtained on potassium acetate surfaces shown in Figures 9 through 13.

The wet and dry landing distances in Table 2 are compared to the appropriate landing field lengths (LFL) in Table 3. These LFLs are calculated using the current dispatch factors. The LFL (dry) is calculated by dividing the AFMLD by a factor of 0.6 (multiplying by 1.67), and the LFL (wet) is calculated by multiplying the LFL (dry) by a factor of 1.15, or multiplying the AFMLD by 1.92. All distances are shown in feet.

Table 3 – Comparison of Landing Distance and Landing Field Length on Wet and Dry Runways

AFMLD	LFL (dry) =AFMLD ×1.67	Excess (dry)	LD (wet)	LFL (wet) =AFMLD × 1.92	Excess (wet)
2000	3333	1333 (40%)	3033	3833	800 (21%)
2400	4000	1600 (40%)	3826	4600	774 (17%)
2800	4667	1866 (40%)	4654	5367	713 (13%)
3200	5333	2133 (40%)	5673	6133	460 (8%)

The difference between the landing distance and the LFL for each case in Table 3 is shown as an "excess," (wet or dry). In the dry runway case, the excess distance increases with increasing AFMLD, and represents a constant 40% of the LFL (dry). In the case of a wet or potassium acetate covered runway, the excess distance decreases with increasing AFMLD, dropping from 21% to 8% of the LFL (wet), considerably below the dry runway safety factor.

These results point to a reduced aircraft tire-to-ground braking coefficient, an increased stopping distance and a reduced safety margin for LFL on wet or potassium acetate covered runways based on current calculation methods. The results are applicable to the specific case of a Falcon 20 landing on a smooth concrete surface, just above the minimum standard for maintenance action, in conditions of light to moderate rainfall or with a single application (water diluted or not) of potassium acetate. Falcon 20 landings on a rougher runway texture with equivalent surface conditions might have resulted in higher braking coefficients, while Falcon 20 landings on the same concrete surface with a double application of potassium acetate would result in lower braking coefficients.

6.0 CONCLUSIONS

The NRC Falcon 20 research aircraft was used to obtain stopping distance data with full anti-skid braking without reverse thrust on potassium acetate covered runway surfaces at the Mirabel airport in March 2004. A total of 11 braking runs were recorded, with four on surfaces with a single application of potassium acetate, two on a surface with a double application of potassium acetate, and five on surfaces with water diluted potassium acetate. Tests were conducted on two different test sections, one on each end of concrete runway 11/29. Test section friction readings were recorded by Saab SFT vehicles before and after each aircraft run, and ERD friction readings were recorded on selected surfaces.

The test objectives listed in section 1.2 were met for the Falcon 20 aircraft. With full anti-skid braking on a smooth concrete runway texture, the aircraft braking coefficients on potassium acetate covered runway surfaces were found to vary in a predictable way with the aircraft groundspeed. Aircraft braking coefficients also varied with the amount and condition of the potassium acetate, being roughly equivalent to those on wet surfaces for a single or water diluted application, and less than those on wet surfaces for a double application.

It is expected that different aircraft types, with anti-skid braking systems similar to that of the Falcon 20, would experience the same equivalence between braking performance on potassium acetate surfaces and braking performance on wet runway surfaces.

The reduction in Falcon 20 braking coefficients on potassium acetate covered runways implied increased landing distances and reduced safety margins for landing field length, with magnitudes similar to those determined during tests on wet runways.

The following specific conclusions are made:

a) SFT friction measurements taken on tanker wet runway surfaces prior to the aircraft tests showed friction variations up to ± 0.10 along the length and width of the test section, as well as differences of up to ± 0.08 between SFT vehicles;

b) SFT friction measurements on potassium acetate runway surfaces were similar to those on wet runway surfaces for a single application of potassium acetate (36 litres per 1000 m^2) or water diluted potassium acetate, and were less than those on wet runway surfaces for a double application of potassium acetate;

c) The limited ERD data obtained were insufficient to confirm the usefulness of the ERD on potassium acetate surfaces;

d) The Falcon 20 mean aircraft braking coefficients correlated well with the mean brake pressures for full anti-skid braking runs on potassium acetate surfaces, similar to the results on wet runway surfaces, and were slightly lower than those on wet surfaces for equivalent brake pressures;

e) For a smooth concrete runway surface, with SFT friction values between 0.50 and 0.70, the Falcon 20 mean aircraft braking coefficients on potassium acetate surfaces were slightly lower than those on wet runway surfaces;

f) The Falcon 20 aircraft braking coefficients decreased consistently with increasing groundspeed for all the braking runs on potassium acetate runway surfaces;

g) The linear relationship between the Falcon 20 braking coefficients and aircraft groundspeed on runway surfaces with a single application of potassium acetate was similar to that for wet runway surfaces.

h) Qualitatively, the Falcon 20 braking performance on surfaces with a single application of potassium acetate, or water diluted potassium acetate, was judged to be similar to that on wet runway surfaces. Falcon 20 braking performance on a surface with a double application of potassium acetate was judged to be less than that on a wet runway surface.

7.0 ACKNOWLEDGEMENTS

The majority of the funding for this project was provided by Transport Canada. The aircraft and ground vehicle tests were conducted safely and effectively due to the dedication and expertise of the combined Transport Canada / NRC test team and their subcontractors. The enthusiasm and support of the Mirabel airport personnel was essential to the success of the project, and is gratefully acknowledged.

8.0 REFERENCES

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7. Rado, Z., Radone, E., *Repeatability and Reproducibility of Saab Friction Measurement Devices in Self-Wet Mode,* Transportation Development Centre, Transport Canada TP 14083E, April 2003.

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APPENDIX A - SUMMARY OF TEST RUNS

APPENDIX A - SUMMARY OF TEST RUNS

The following table shows the test conditions for all test runs on potassium acetate surfaces. The table columns, from the left, include the flight number and date, the run number and local time, the runway used, the aircraft manoeuvre used (taxi, accel/stop or landing), the aircraft configuration, the aircraft weight, the tower reported wind, the runway surface description, the SFT readings and average, and the aircraft CG arm where applicable.

Pages A2 to A8 show the time histories of left and right brake pressures, aircraft ground speed, and aircraft braking coefficient (MuB) for all test runs, with two runs per page. Selected statistics for each parameter are shown in small print above each plot. The aircraft MuB shown is the MuB calculated in equation 1 (section 4.0 of this report) from raw recorded data at a sample rate of 32 samples per second. For the taxi runs and coasting runs (no brakes) the brake pressures are zero, and MuB reduces to the aircraft rolling friction coefficient.

FLT/ DATE	RUN/ Time	RW	TAXI/ RTO/ LAND	CONFIG (see Note 1)	Weight (LB)	TWR Wind (Kn)	SURFACE DESCRIPTION And Comments	Avg SFT RFI (see Note 2)	CG ARM (in)
2004/01 9/3/04	1 1322	29	Taxi	15/IN/NO	24,412	105/4	100% Bare and dry		
	2 1344	11	Accel/ Stop	40/EXT/B	24,012	080/5	One application K-acetate	0.61/0.59 0.60	22.52
	3 1351	11	Accel/ Stop	40/EXT/B	23,862	095/3	K-acetate remaining	0.58/0.57 0.58	22.44
	4 1416	11	LAND	40/EXT/B	23,162	110/4	Second application K-acetate	0.54/0.49 0.51	21.98
	5 1428	11	LAND	40/EXT/B	22,712	200/5	K-acetate remaining	0.54/0.48 0.51	21.73
	6 1449	11	Accel/ Stop	40/EXT/B	22,262	170/6	Water diluted K-acetate	0.52/0.59 0.55	21.41
	7 1459	11	LAND	40/EXT/B	21,662	175/5	Water diluted K-acetate remaining	0.54/0.62 0.58	21.28
	8 1511	11	LAND	40/EXT/B	21,512	200/5	Water diluted K-acetate remaining	0.58/0.64 0.61	21.32
2004/02 10/3/04	1 1023	11	Taxi	15/IN/NO	24,412	Calm	100% Bare and dry NO DATA		
	2 1041	29	Accel/ Stop	40/EXT/B	24,062	190/1	One application K-acetate	0.71/0.70 0.70	22.55
	3 1053	29	LAND	40/EXT/B	23,812	Calm	K-acetate remaining	0.68/0.67 0.67	22.41
	4 1120	29	Accel/ Stop	40/EXT/B	23,312	200/3	Water diluted K-acetate	0.57/0.65 0.61	22.07
	5 1133	29	LAND	40/EXT/B	22,812	190/3	Water diluted K-acetate remaining	0.68/0.67 0.67	21.76
	6 1142	11	Taxi	15/IN/NO	22,512	200/3	100% Bare and dry		

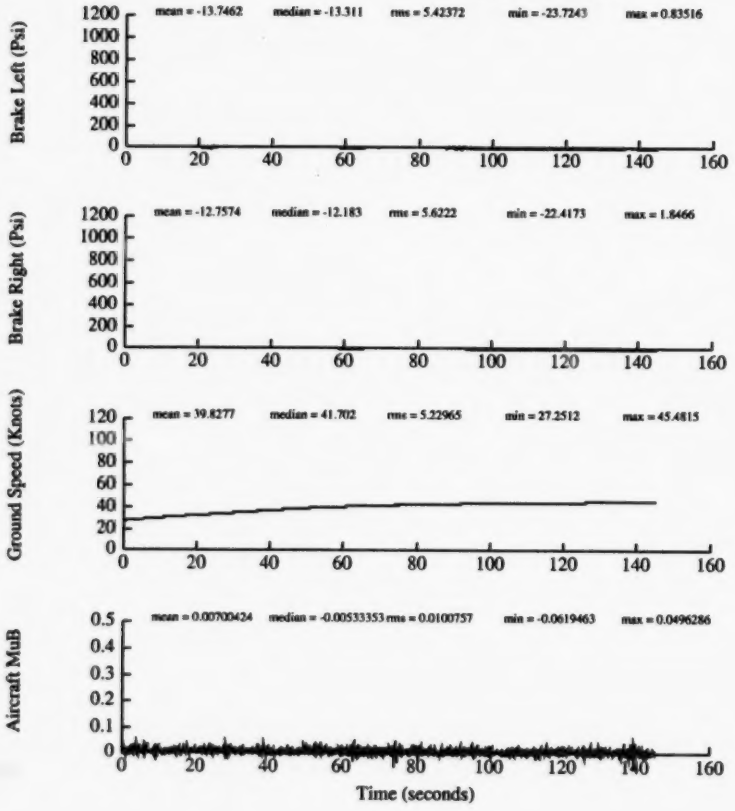
Note 1: Indicates flap setting (15 or 40), airbrake position (IN or EXT) and pilot braking (NO for no braking, B for maximum anti-skid braking)

Note 2: Tradewind SFT / TC SFT Turbo
Average

C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2004/1, Run 1 9-March-2004

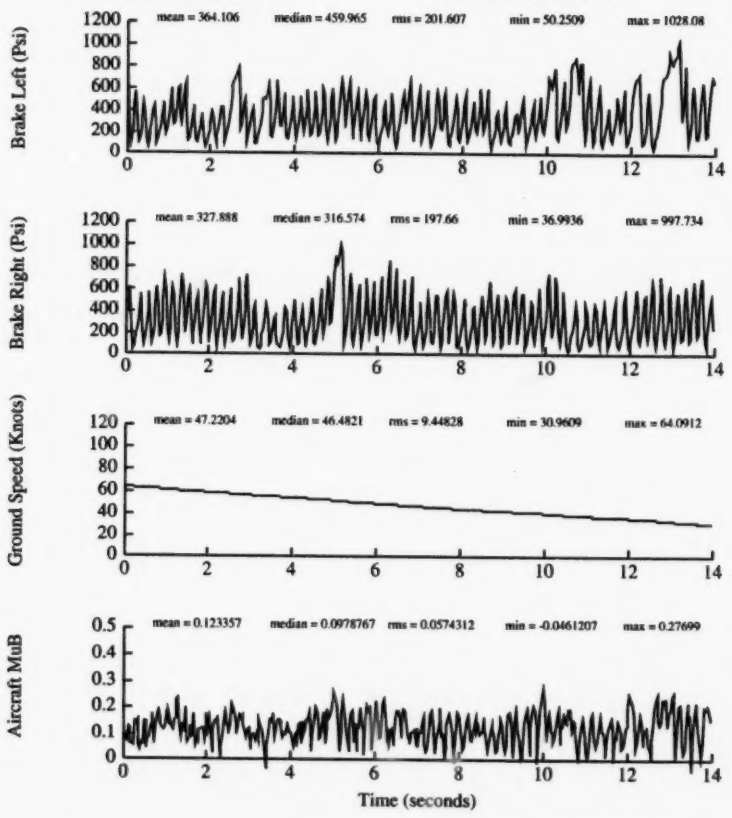
100% Bare and Dry Runway 29, Wind 105/4


Brake Left (Psi)
mean = -13.7462 median = -13.311 rms = 5.42372 min = -23.7243 max = 0.83516
Brake Right (Psi)
mean = -12.7574 median = -12.183 rms = 5.6222 min = -22.4173 max = 1.8466
Ground Speed (Knots)
mean = 39.8277 median = 41.702 rms = 5.22965 min = 27.2512 max = 45.4815
Aircraft MuB
mean = 0.00700424 median = -0.00533353 rms = 0.0100757 min = -0.0619463 max = 0.0496286
Time (seconds)

C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2004/1, Run 2 9-March-2004

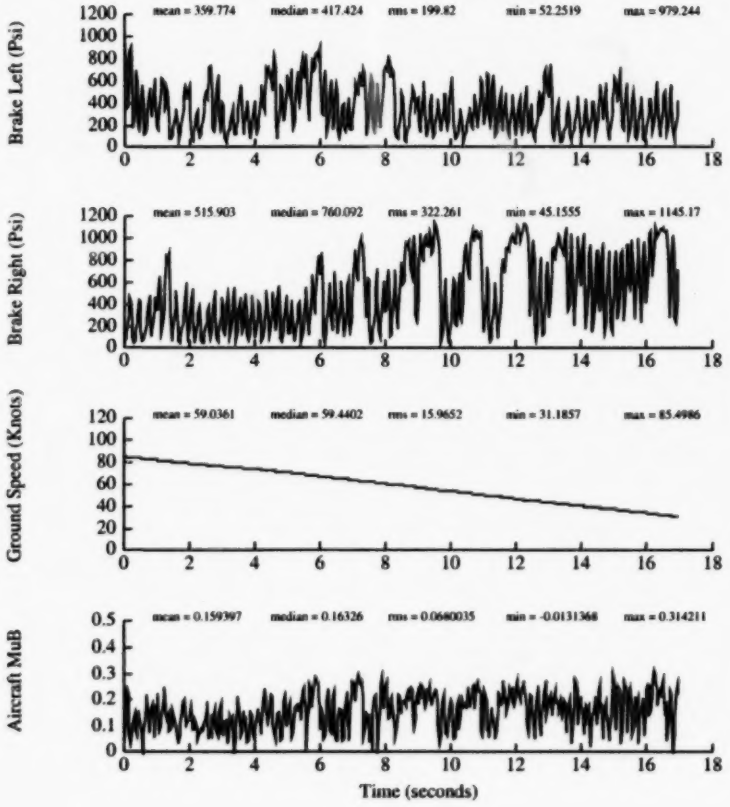
One Application K-acetate Runway 11, Wind 80/5


Brake Left (Psi)
mean = 364.106 median = 459.965 rms = 201.607 min = 50.2509 max = 1028.08
Brake Right (Psi)
mean = 327.888 median = 316.574 rms = 197.66 min = 36.9936 max = 997.734
Ground Speed (Knots)
mean = 47.2204 median = 46.4821 rms = 9.44828 min = 30.9609 max = 64.0912
Aircraft MuB
mean = 0.123357 median = 0.0978767 rms = 0.0574312 min = -0.0461207 max = 0.27699
Time (seconds)

C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2004/1, Run 3 9-March-2004

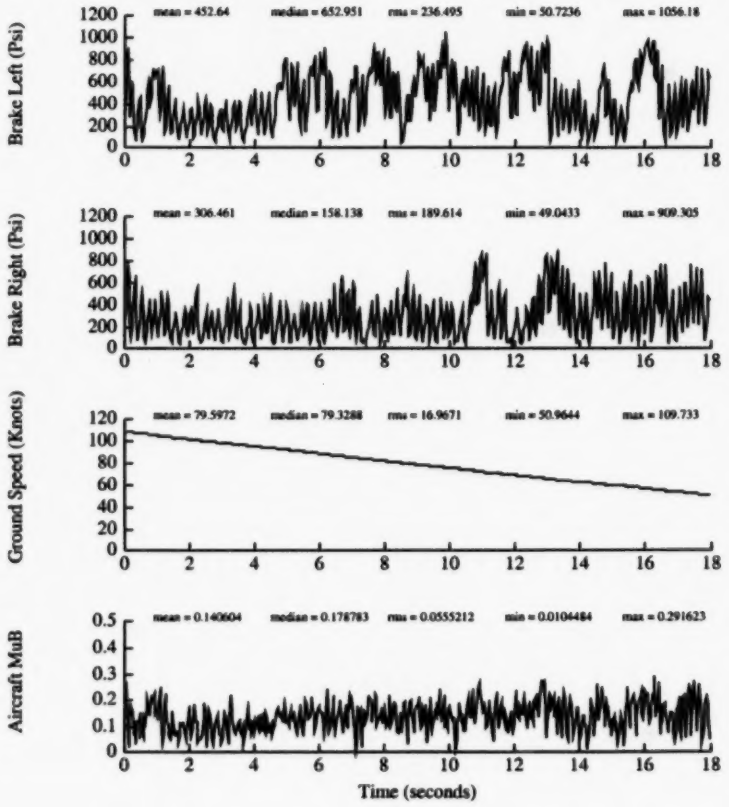
K-acetate Remaining Runway 11, Wind 95/3

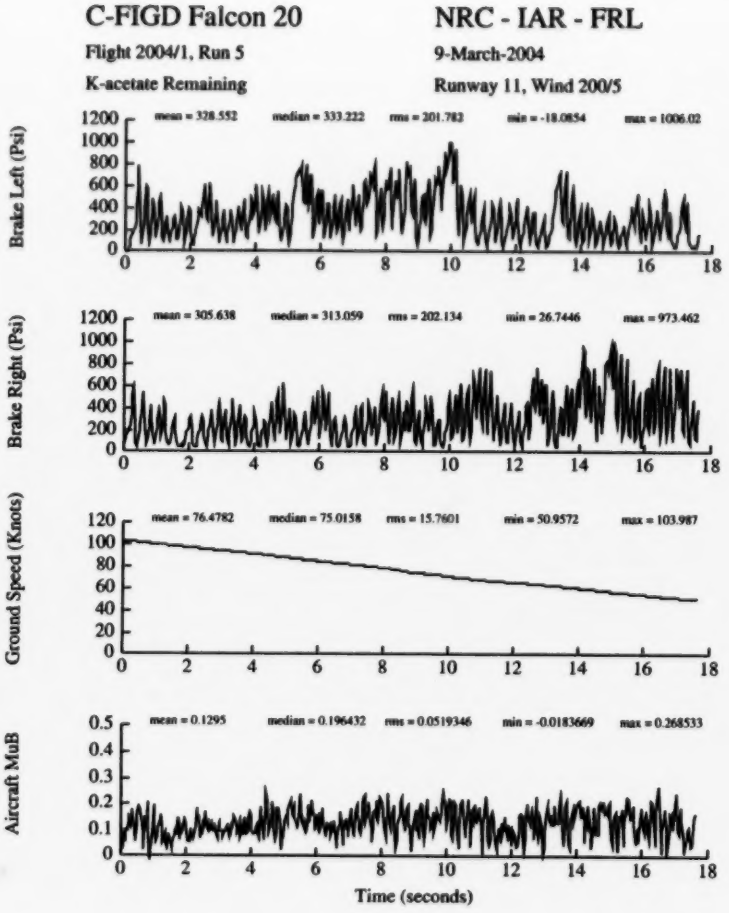

Brake Left (Psi)
mean = 359.774 median = 417.424 rms = 199.82 min = 52.2519 max = 979.244
Brake Right (Psi)
mean = 515.903 median = 760.092 rms = 322.261 min = 45.1555 max = 1145.17
Ground Speed (Knots)
mean = 59.0361 median = 59.4402 rms = 15.9652 min = 31.1857 max = 85.4986
Aircraft MuB
mean = 0.159397 median = 0.16326 rms = 0.0680035 min = -0.0131368 max = 0.314211
Time (seconds)

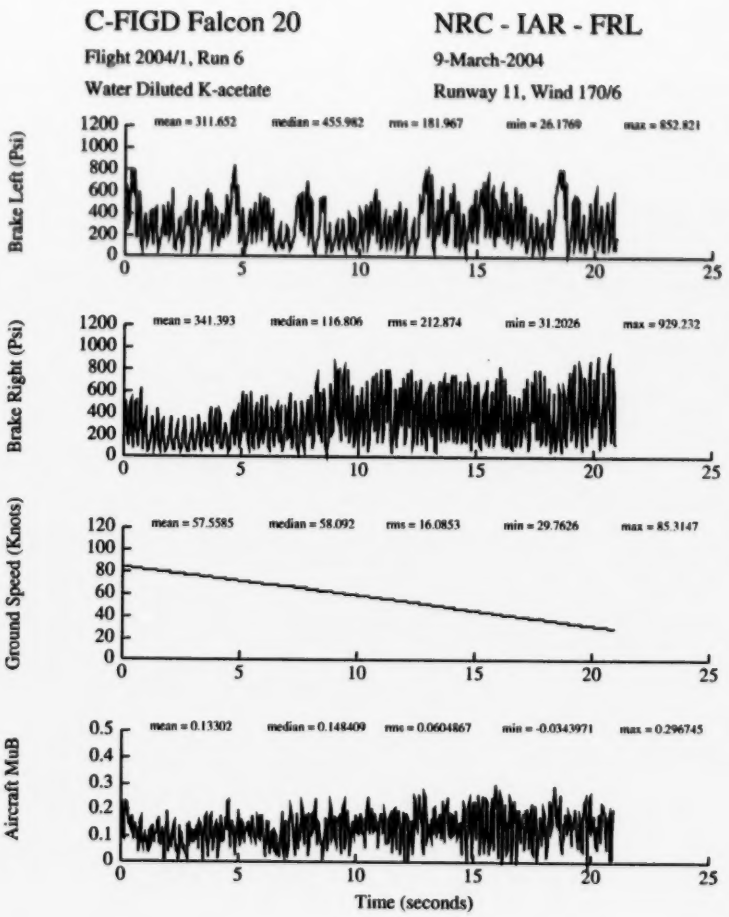
C-FIGD Falcon 20 NRC - IAR - FRL

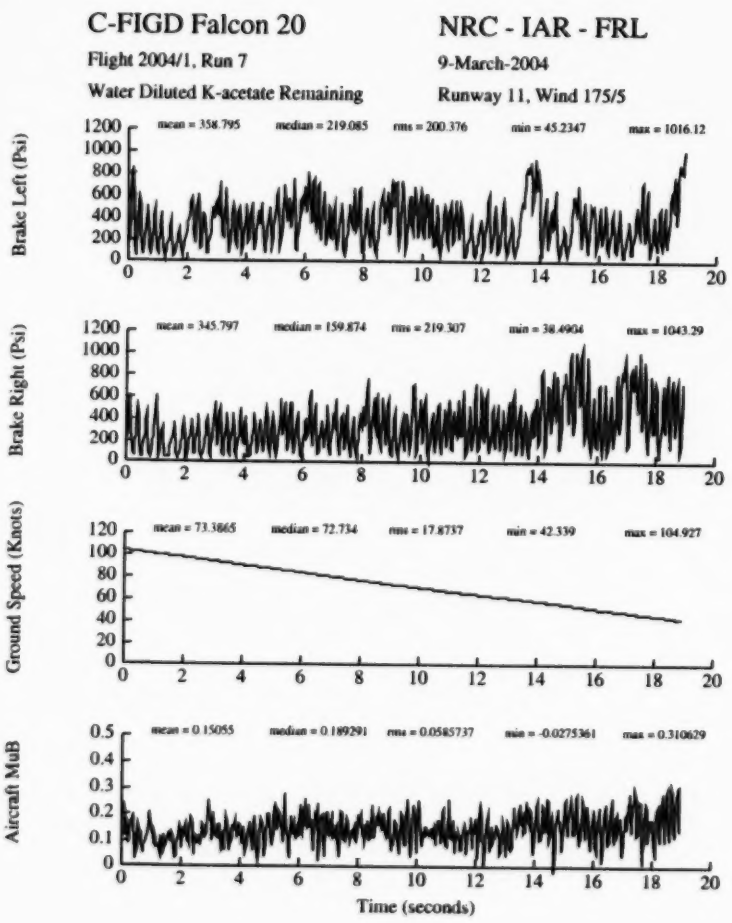
Flight 2004/1, Run 4 9-March-2004

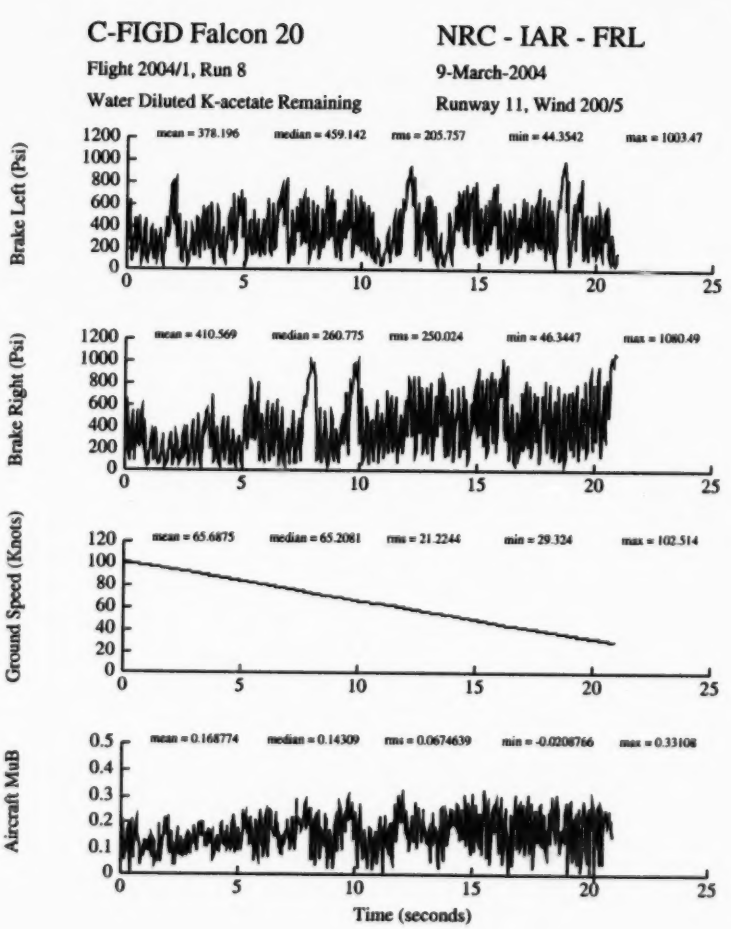
Second Application of K-acetate Runway 11, Wind 110/4

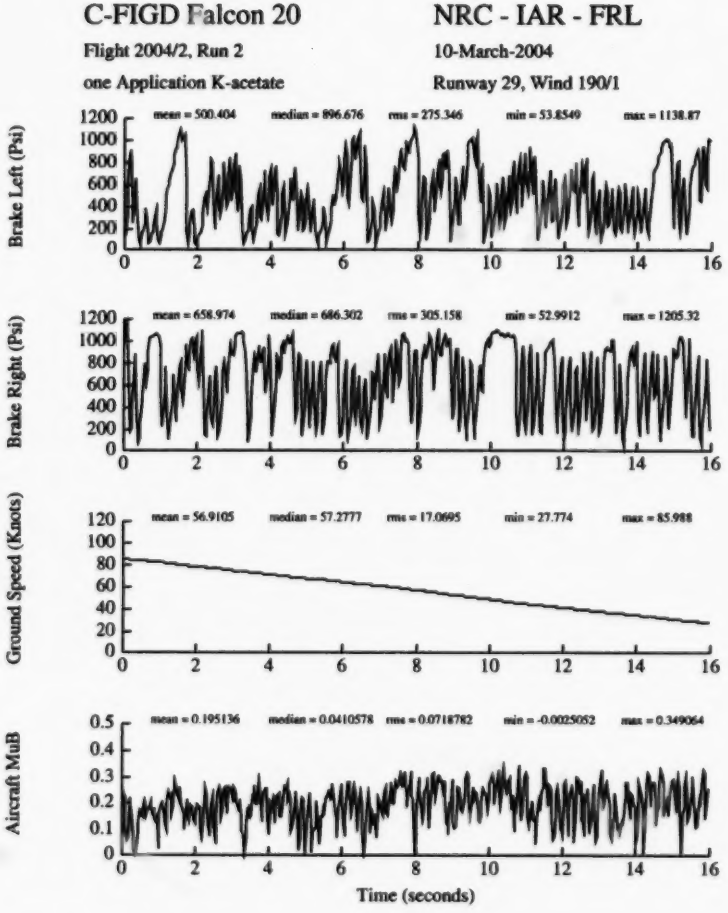

Brake Left (Psi)
mean = 452.64 median = 652.951 rms = 236.495 min = 50.7236 max = 1056.18
Brake Right (Psi)
mean = 306.461 median = 158.138 rms = 189.614 min = 49.0433 max = 909.305
Ground Speed (Knots)
mean = 79.5972 median = 79.3288 rms = 16.9671 min = 50.9644 max = 109.733
Aircraft MuB
mean = 0.140604 median = 0.178783 rms = 0.0555212 min = 0.0104484 max = 0.291623
Time (seconds)

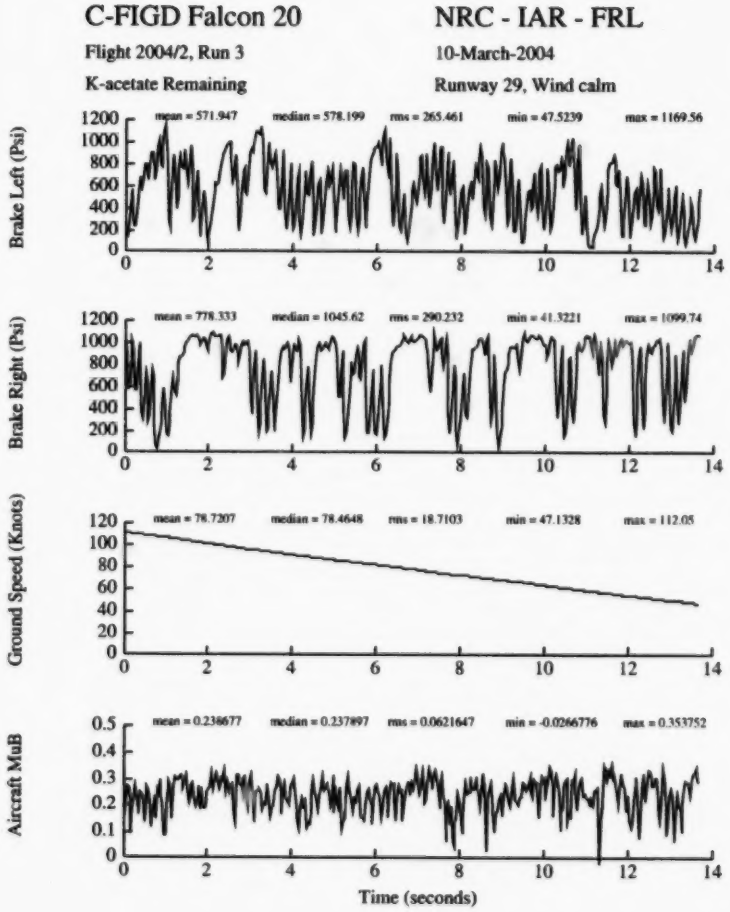

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2004/1, Run 5
9-March-2004
K-acetate Remaining
Runway 11, Wind 200/5
Brake Left (Psi)
mean = 328.552 median = 333.222 rms = 201.782 min = -18.0854 max = 1006.02
Brake Right (Psi)
mean = 305.638 median = 313.059 rms = 202.134 min = 26.7446 max = 973.462
Ground Speed (Knots)
mean = 76.4782 median = 75.0158 rms = 15.7601 min = 50.9572 max = 103.987
Aircraft MuB
mean = 0.1295 median = 0.196432 rms = 0.0519346 min = -0.0183669 max = 0.268533
Time (seconds)

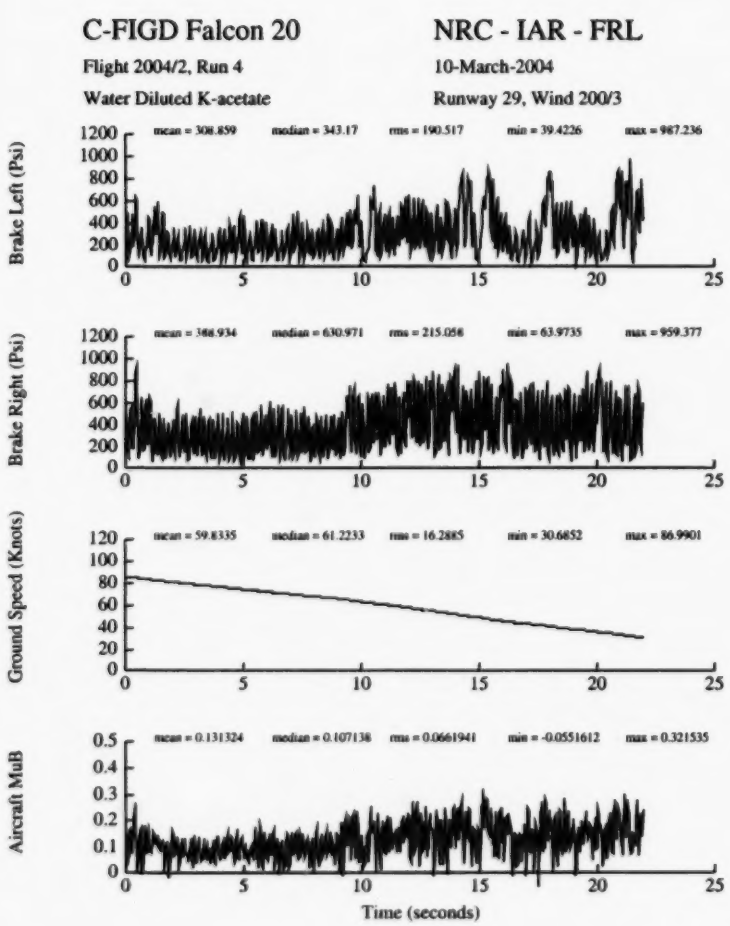

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2004/1, Run 6
9-March-2004
Water Diluted K-acetate
Runway 11, Wind 170/6
Brake Left (Psi)
mean = 311.652 median = 455.982 rms = 181.967 min = 26.1769 max = 852.821
Brake Right (Psi)
mean = 341.393 median = 116.806 rms = 212.874 min = 31.2026 max = 929.232
Ground Speed (Knots)
mean = 57.5585 median = 58.092 rms = 16.0853 min = 29.7626 max = 85.3147
Aircraft MuB
mean = 0.13302 median = 0.148409 rms = 0.0604867 min = -0.0343971 max = 0.296745
Time (seconds)

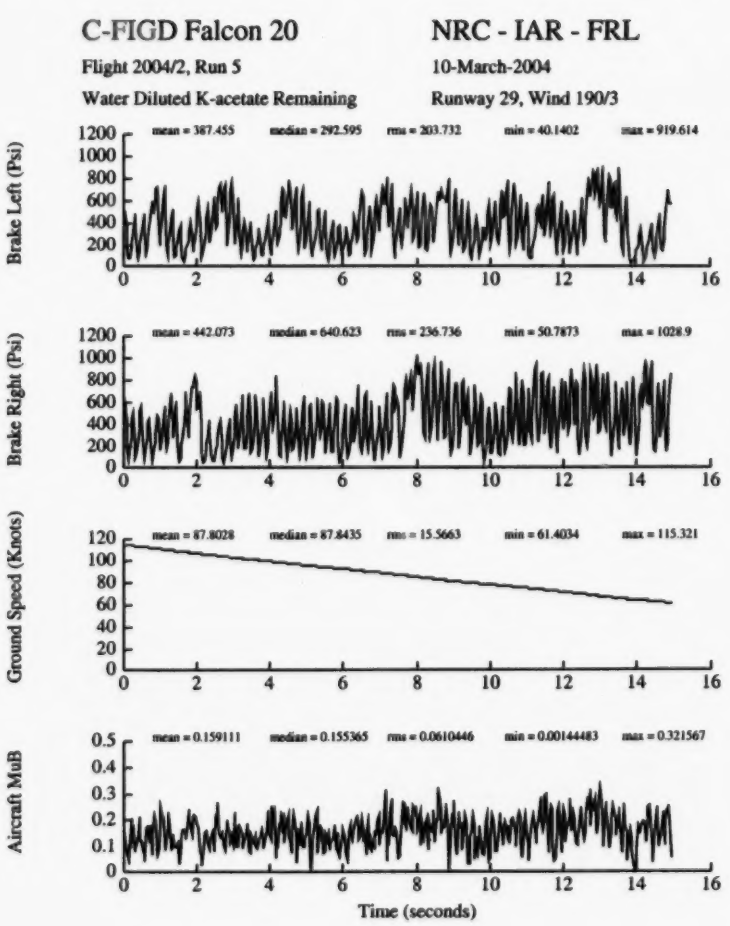

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2004/1, Run 7
9-March-2004
Water Diluted K-acetate Remaining
Runway 11, Wind 175/5
Brake Left (Psi)
mean = 358.795 median = 219.085 rms = 200.376 min = 45.2347 max = 1016.12
Brake Right (Psi)
mean = 345.797 median = 159.874 rms = 219.307 min = 38.4904 max = 1043.29
Ground Speed (Knots)
mean = 73.3865 median = 72.734 rms = 17.8737 min = 42.339 max = 104.927
Aircraft MuB
mean = 0.15055 median = 0.189291 rms = 0.0585737 min = -0.0275361 max = 0.310629
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2004/1, Run 8
9-March-2004
Water Diluted K-acetate Remaining
Runway 11, Wind 200/5
Brake Left (Psi)
mean = 378.196 median = 459.142 rms = 205.757 min = 44.3542 max = 1003.47
Brake Right (Psi)
mean = 410.569 median = 260.775 rms = 250.024 min = 46.3447 max = 1080.49
Ground Speed (Knots)
mean = 65.6875 median = 65.2081 rms = 21.2244 min = 29.324 max = 102.514
Aircraft MuB
mean = 0.168774 median = 0.14309 rms = 0.0674639 min = -0.0208766 max = 0.33108
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2004/2, Run 2
10-March-2004
one Application K-acetate
Runway 29, Wind 190/1
Brake Left (Psi)
mean = 500.404 median = 896.676 rms = 275.346 min = 53.8549 max = 1138.87
Brake Right (Psi)
mean = 658.974 median = 686.302 rms = 305.158 min = 52.9912 max = 1205.32
Ground Speed (Knots)
mean = 56.9105 median = 57.2777 rms = 17.0695 min = 27.774 max = 85.988
Aircraft MuB
mean = 0.195136 median = 0.0410578 rms = 0.0718782 min = -0.0025052 max = 0.349064
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2004/2, Run 3
10-March-2004
K-acetate Remaining
Runway 29, Wind calm
Brake Left (Psi)
mean = 571.947 median = 578.199 rms = 265.461 min = 47.5239 max = 1169.56
Brake Right (Psi)
mean = 778.333 median = 1045.62 rms = 290.232 min = 41.3221 max = 1099.74
Ground Speed (Knots)
mean = 78.7207 median = 78.4648 rms = 18.7103 min = 47.1328 max = 112.05
Aircraft MuB
mean = 0.238677 median = 0.237897 rms = 0.0621647 min = -0.0266776 max = 0.353752
Time (seconds)

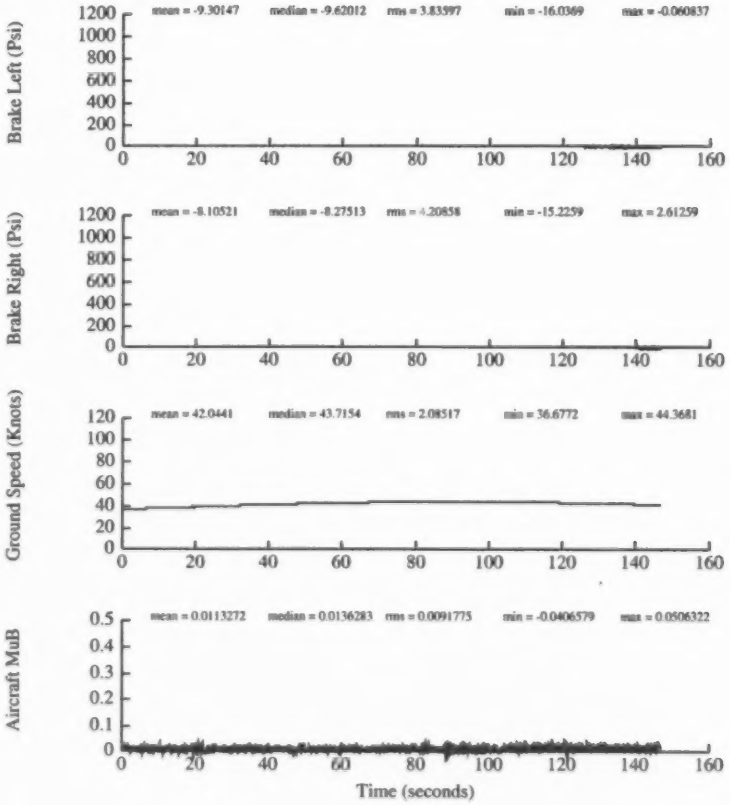

C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2004/2, Run 4
10-March-2004
Water Diluted K-acetate
Runway 29, Wind 200/3
Brake Left (Psi)
mean = 308.859 median = 343.17 rms = 190.517 min = 39.4226 max = 987.236
Brake Right (Psi)
mean = 388.934 median = 630.971 rms = 215.056 min = 63.9735 max = 959.377
Ground Speed (Knots)
mean = 59.8335 median = 61.2233 rms = 16.2885 min = 30.6852 max = 86.9901
Aircraft MuB
mean = 0.131324 median = 0.107138 rms = 0.0661941 min = -0.0551612 max = 0.321535
Time (seconds)


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2004/2, Run 5
10-March-2004
Water Diluted K-acetate Remaining
Runway 29, Wind 190/3
Brake Left (Psi)
mean = 387.455 median = 292.595 rms = 203.732 min = 40.1402 max = 919.614
Brake Right (Psi)
mean = 442.073 median = 640.623 rms = 236.736 min = 50.7873 max = 1028.9
Ground Speed (Knots)
mean = 87.8028 median = 87.8435 rms = 15.5663 min = 61.4034 max = 115.321
Aircraft MuB
mean = 0.159111 median = 0.155365 rms = 0.0610446 min = 0.00144483 max = 0.321567
Time (seconds)

C-FIGD Falcon 20 NRC - IAR - FRL

Flight 2004/2, Run 6 10-March-2004

100% Bare and Dry Runway 11, Wind 200/3


Brake Left (Psi)
mean = -9.30147 median = -9.62012 rms = 3.83597 min = -16.0369 max = -0.060837
Brake Right (Psi)
mean = -8.10521 median = -8.27513 rms = 4.20858 min = -15.2259 max = 2.61259
Ground Speed (Knots)
mean = 42.0441 median = 43.7154 rms = 2.08517 min = 36.6772 max = 44.3681
Aircraft MuB
mean = 0.0113272 median = 0.0136283 rms = 0.0091775 min = -0.0406579 max = 0.0506322
Time (seconds)

APPENDIX B - TEST RUNS FOR AIRCRAFT BRAKING COEFFICIENT

APPENDIX B - TEST RUNS FOR AIRCRAFT BRAKING COEFFICIENT

The following table shows the test runs used to determine the aircraft braking coefficients (MuB, or μ_B) on potassium acetate surfaces. The table columns, from the left, include the flight number and date, the run number and local time, the runway used, the aircraft manoeuvre used (taxi, accel/stop or landing), the aircraft configuration, the runway surface description, the mean SFT reading, the mean aircraft groundspeed, the mean aircraft μ_B, and the coefficients of a linear regression between μ_B and groundspeed. Values of mean μ_B and mean groundspeed shown in the table are taken from the charts in Appendix A.

Pages B2 to B7 show the variation of a smoothed aircraft μ_B parameter with aircraft groundspeed for each braking run, two runs per page. The smoothed μ_B parameter is calculated by taking a one second average (16 samples on either side) of each recorded μ_B sample. This procedure filters out the variations of μ_B resulting from anti-skid action, but retains the variations of μ_B resulting from changes in surface wetness or texture. The coefficients C0 and C1 shown in the table are taken from the charts in this Appendix.

FLT/ Date	RUN/ Time	RW	TAXI/ RTO/ LAND	CONFIG see note 1	Surface Description	Mean SFT note 2	MEAN SPEED (Kn GS)	MEAN μ_B	Coefficients	
									C0	C1
2004/01 9/3/04	2 1344	11	Accel/ Stop	40/EXT/B	One application K-acetate	0.60	47.2	0.123	0.137	-0.00029
	3 1351	11	Accel/ Stop	40/EXT/B	K-acetate remaining	0.58	59.0	0.159	0.236	-0.00128
	4 1416	11	LAND	40/EXT/B	Second application K-acetate	0.51	79.6	0.141	0.201	-0.00077
	5 1428	11	LAND	40/EXT/B	K-acetate remaining	0.51	76.5	0.130	0.178	-0.00064
	6 1449	11	Accel/ Stop	40/EXT/B	Water diluted K-acetate	0.55	57.6	0.133	0.187	-0.00095
	7 1459	11	LAND	40/EXT/B	Water diluted K-acetate remaining	0.58	73.4	0.151	0.226	-0.00104
	8 1511	11	LAND	40/EXT/B	Water diluted K-acetate remaining	0.61	65.7	0.169	0.232	-0.00098
2004/02 10/3/04	2 1041	29	Accel/ Stop	40/EXT/B	One application K-acetate	0.70	56.9	0.195	0.244	-0.00086
	3 1053	29	LAND	40/EXT/B	K-acetate remaining	0.67	78.7	0.239	0.249	-0.00012
	4 1120	29	Accel/ Stop	40/EXT/B	Water diluted K-acetate	0.61	59.8	0.131	0.220	-0.00148
	5 1133	29	LAND	40/EXT/B	Water diluted K-acetate remaining	0.67	87.8	0.159	0.228	-0.00078

Note 1: Indicates flap setting (15 or 40), airbrake position (IN or EXT) and pilot braking (NO for no braking, B for maximum anti-skid braking)

Note 2: Average of Tradewind SFT and TC SFT Turbo

C-FIGD Falcon 20

Flight 2004/1, Run 2

One Application K-acetate

NRC - IAR - FRL

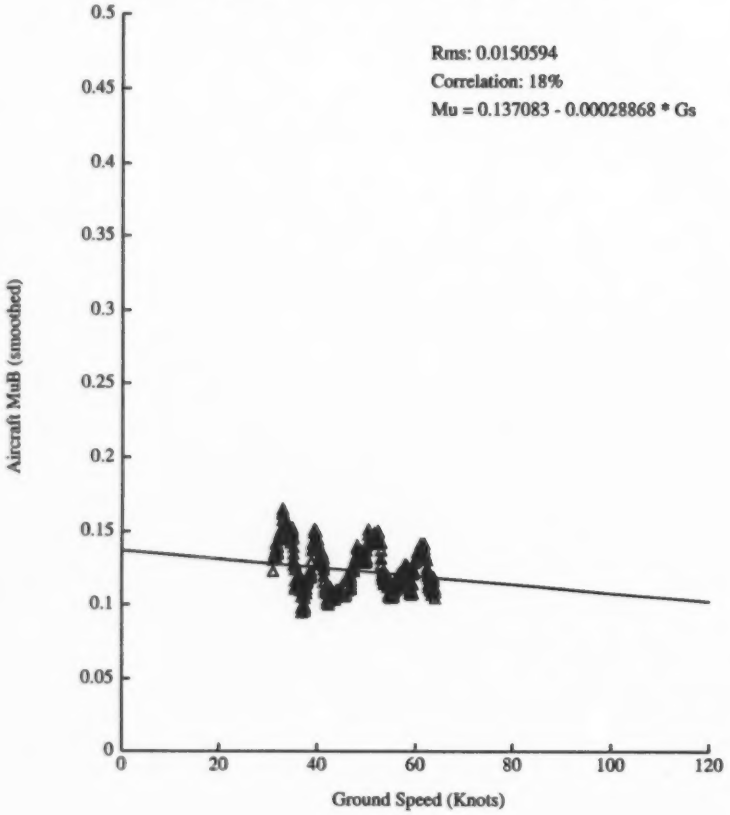
9-March-2004

Runway 11, Wind 80/5

Rms: 0.0150594

Correlation: 18%

Mu = 0.137083 - 0.00028868 * Gs



C-FIGD Falcon 20

Flight 2004/1, Run 3

K-acetate Remaining

NRC - IAR - FRL

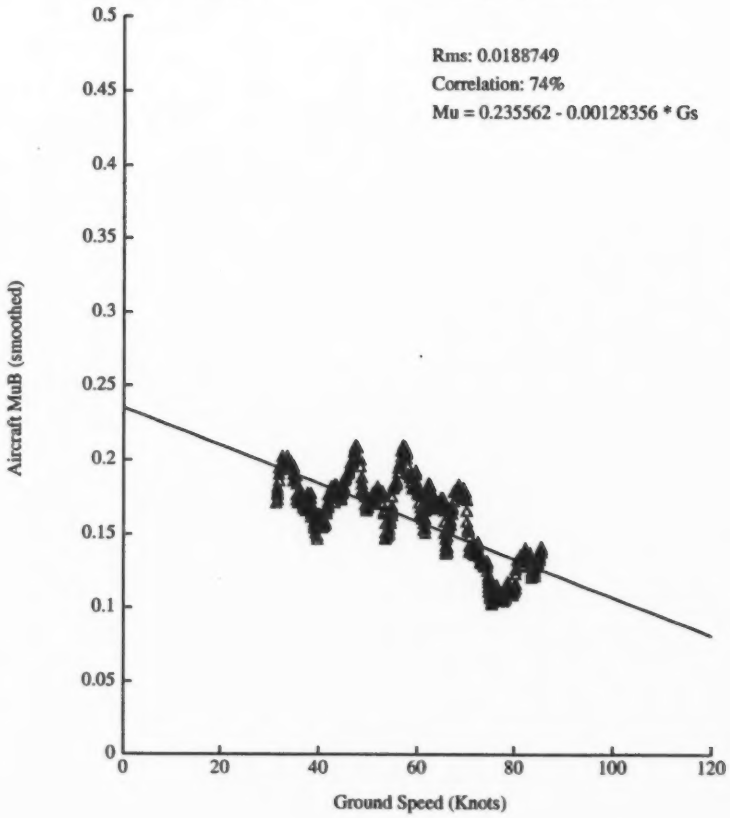
9-March-2004

Runway 11, Wind 95/3

Rms: 0.0188749

Correlation: 74%

Mu = 0.235562 - 0.00128356 * Gs



C-FIGD Falcon 20

Flight 2004/1, Run 4

Second Application of K-acetate

NRC - IAR - FRL

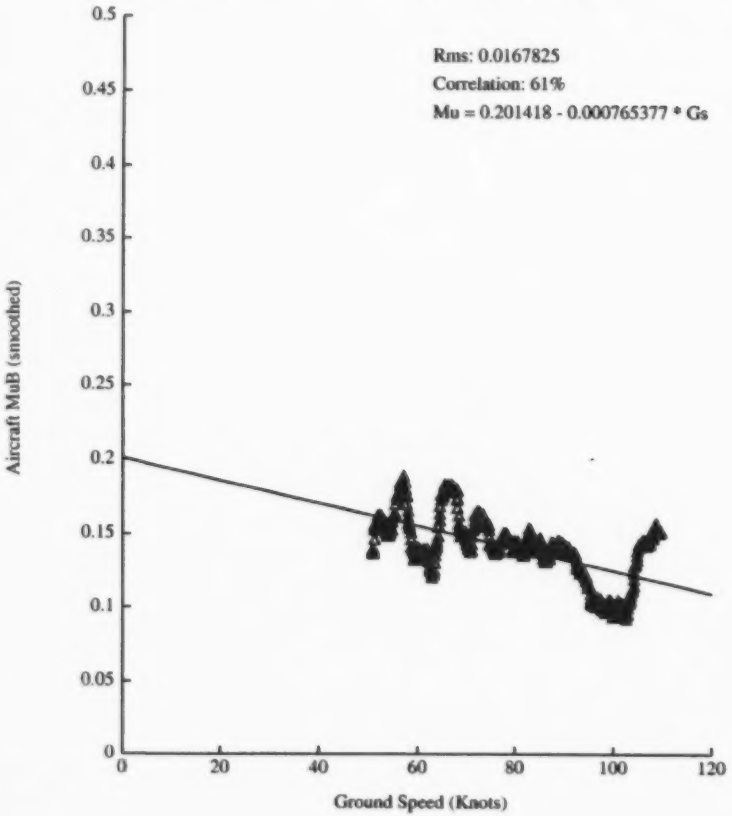
9-March-2004

Runway 11, Wind 110/4

Rms: 0.0167825

Correlation: 61%

Mu = 0.201418 - 0.000765377 * Gs



C-FIGD Falcon 20

Flight 2004/1, Run 5

K-acetate Remaining

NRC - IAR - FRL

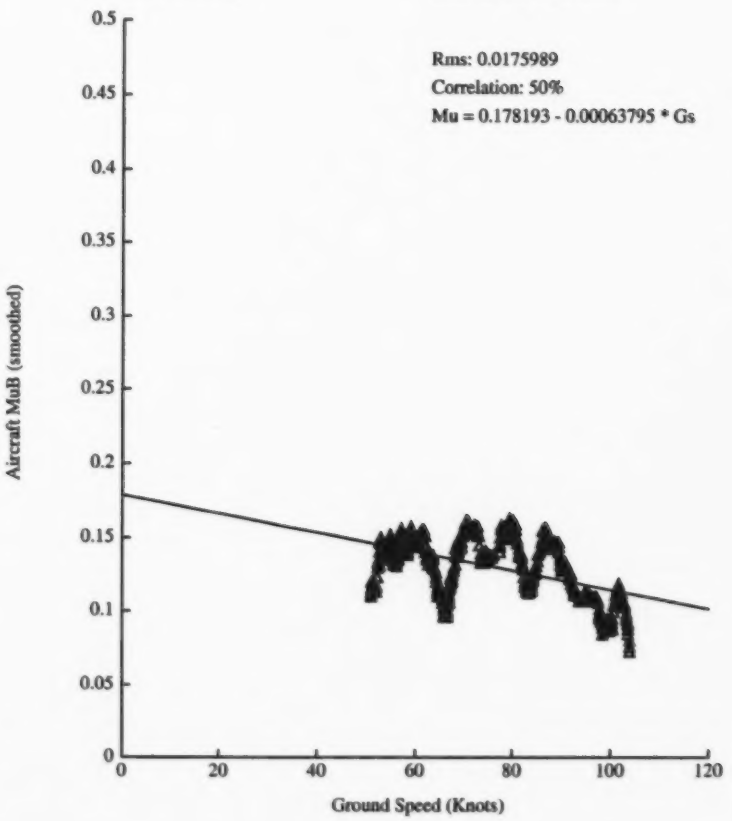
9-March-2004

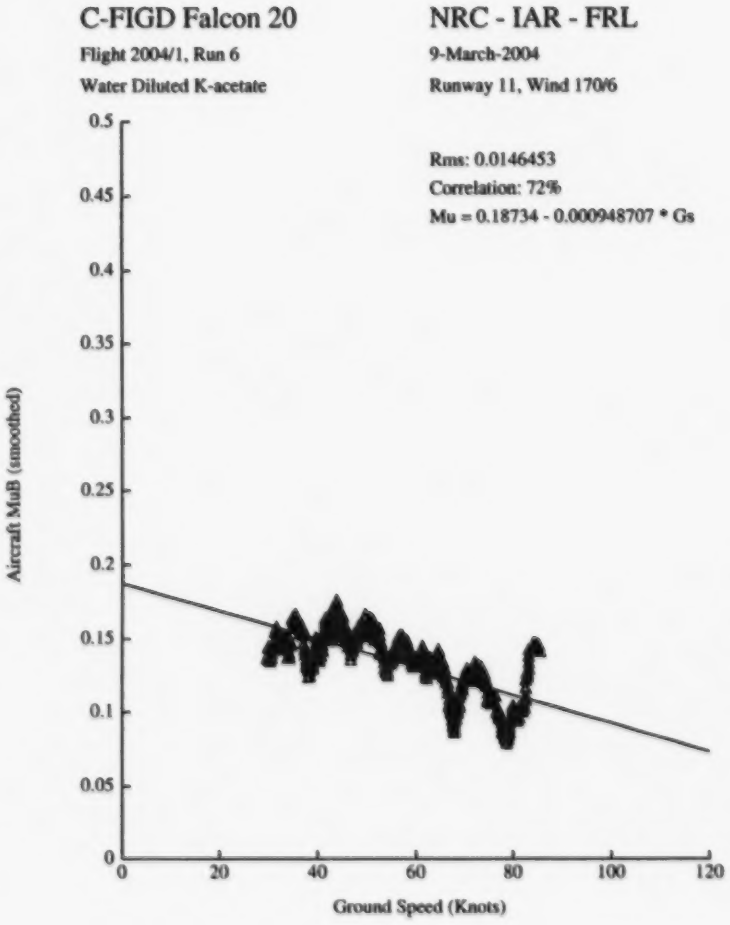
Runway 11, Wind 200/5

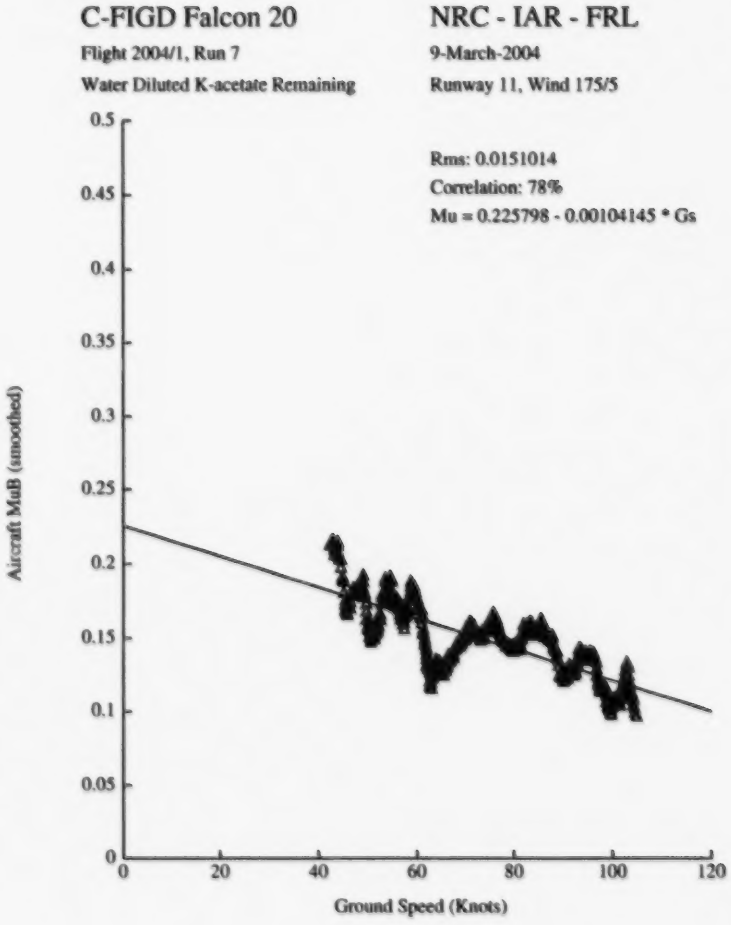
Rms: 0.0175989

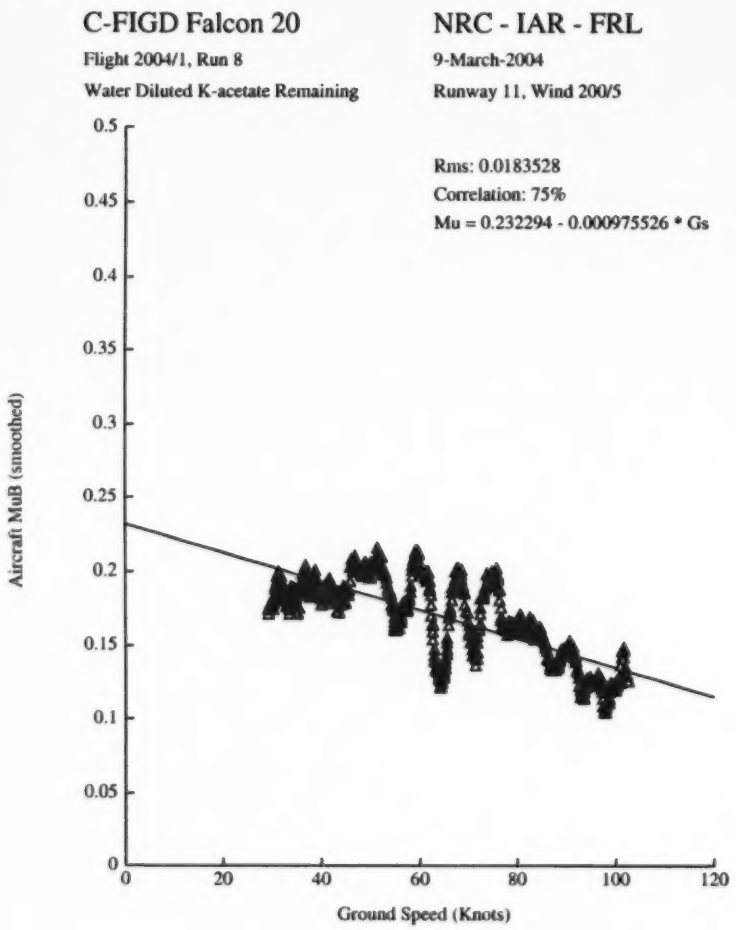
Correlation: 50%

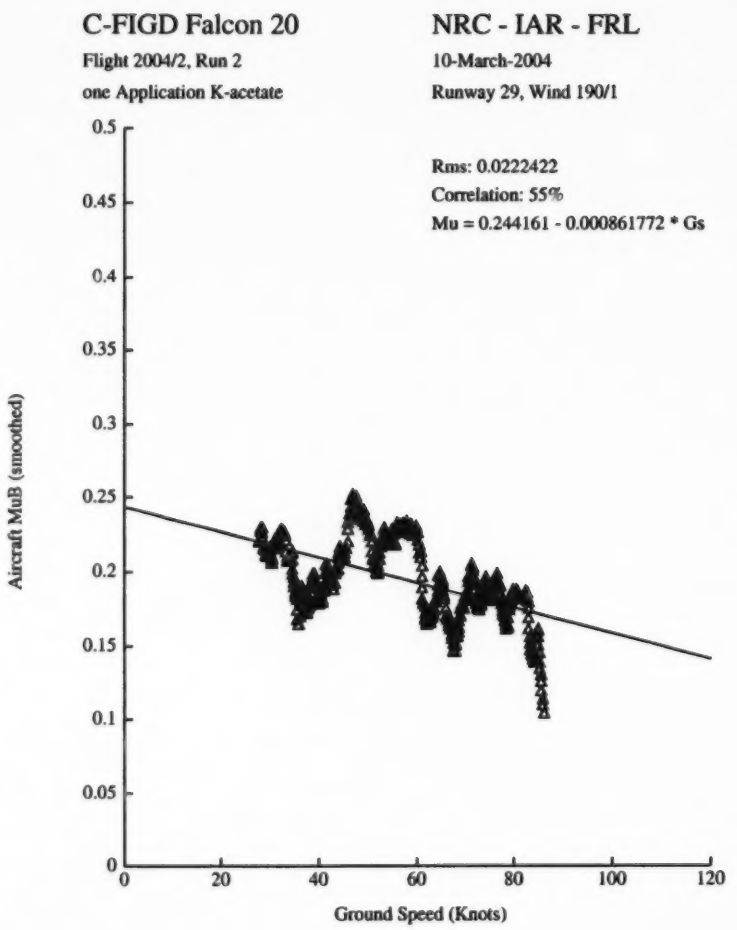
Mu = 0.178193 - 0.00063795 * Gs

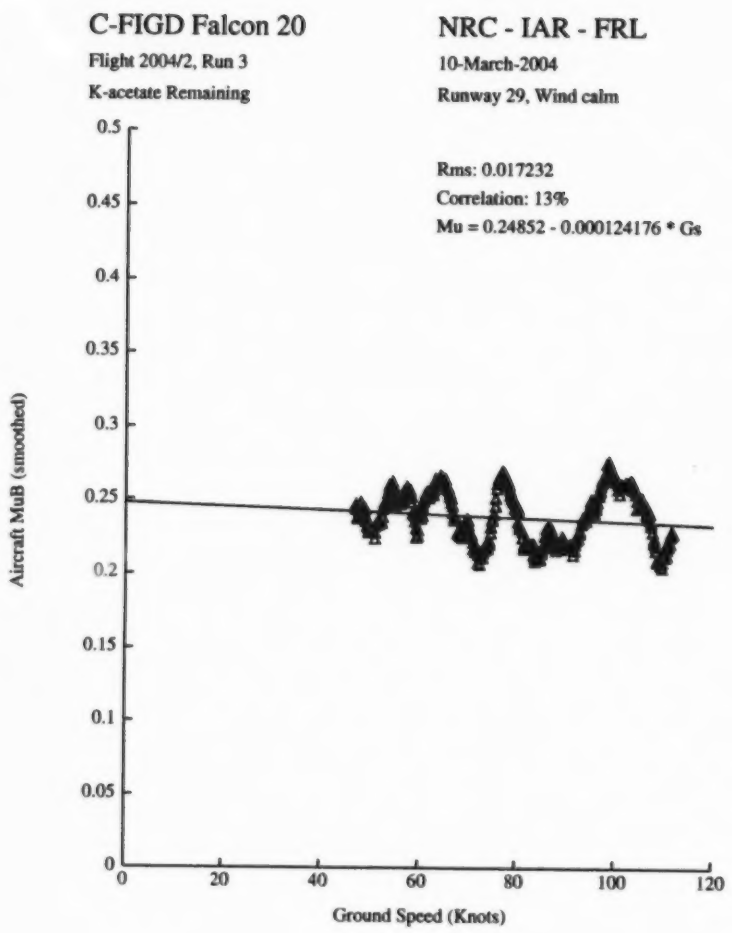


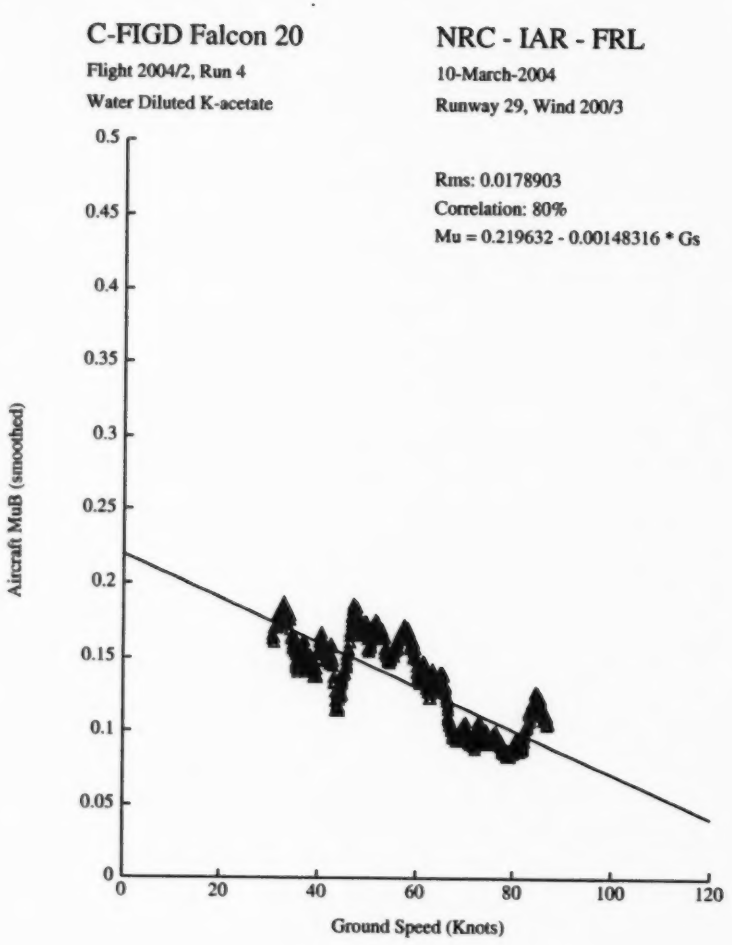

C-FIGD Falcon 20
Flight 2004/1, Run 6
Water Diluted K-acetate
NRC - IAR - FRL
9-March-2004
Runway 11, Wind 170/6
Rms: 0.0146453
Correlation: 72%
Mu = 0.18734 - 0.000948707 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120

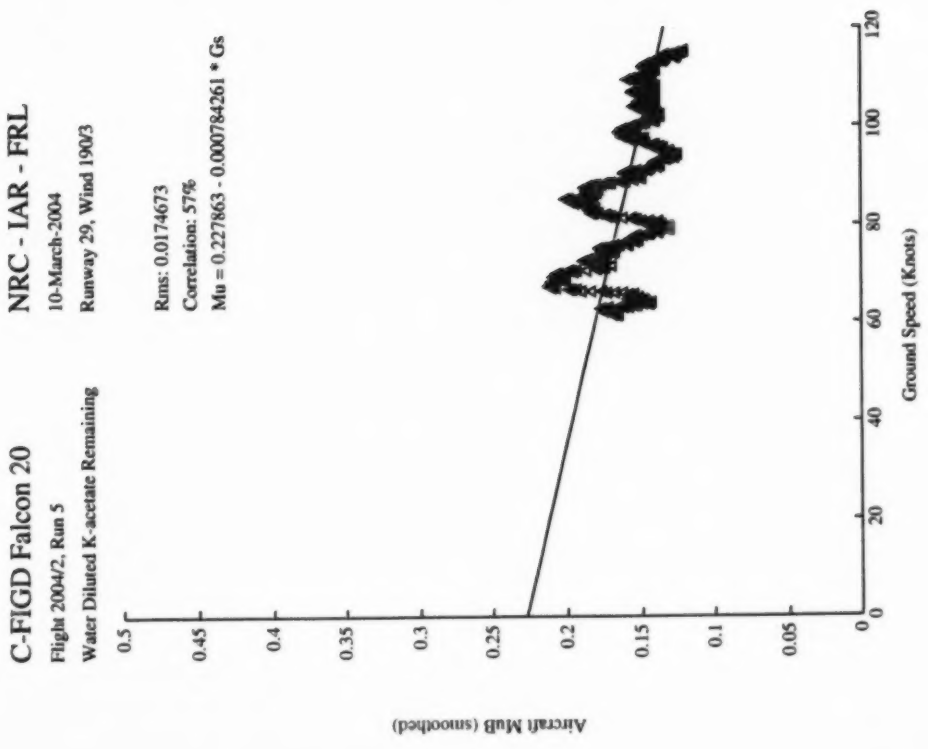

C-FIGD Falcon 20
Flight 2004/1, Run 7
Water Diluted K-acetate Remaining
NRC - IAR - FRL
9-March-2004
Runway 11, Wind 175/5
Rms: 0.0151014
Correlation: 78%
Mu = 0.225798 - 0.00104145 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2004/1, Run 8
Water Diluted K-acetate Remaining
NRC - IAR - FRL
9-March-2004
Runway 11, Wind 200/5
Rms: 0.0183528
Correlation: 75%
Mu = 0.232294 - 0.000975526 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2004/2, Run 2
one Application K-acetate
NRC - IAR - FRL
10-March-2004
Runway 29, Wind 190/1
Rms: 0.0222422
Correlation: 55%
Mu = 0.244161 - 0.000861772 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2004/2, Run 3
K-acetate Remaining
NRC - IAR - FRL
10-March-2004
Runway 29, Wind calm
Rms: 0.017232
Correlation: 13%
Mu = 0.24852 - 0.000124176 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120


C-FIGD Falcon 20
Flight 2004/2, Run 4
Water Diluted K-acetate
NRC - IAR - FRL
10-March-2004
Runway 29, Wind 200/3
Rms: 0.0178903
Correlation: 80%
Mu = 0.219632 - 0.00148316 * Gs
Aircraft MuB (smoothed)
Ground Speed (Knots)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120


C-FIGD Falcon 20
NRC - IAR - FRL
Flight 2004/2, Run 5
10-March-2004
Water Diluted K-acetate Remaining
Runway 29, Wind 190/3
Rms: 0.0174673
Correlation: 57%
Mu = 0.227863 - 0.000784261 * Gs
Aircraft Mub (smoothed)
Ground Speed (Knots)
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
20
40
60
80
100
120